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ILLUMINATING ENGINEERING SOCIETY

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Contents

87 **A Survey of Drawing Office Lighting Requirements**
J. B. Collins B.SC. (ENG.) A.M.I.E.E. (FELLOW) and F. J. LANGDON B.A. D.PHIL.

115 **Application of Regulations Relating to the Lighting of Ships**
J. T. Grundy (MEMBER)

131 **A Note on Calculations of Disability Glare, Veiling and Contrast**
J. M. Waldram B.SC. (FELLOW)

135 **A Note on the Use of Indices of Glare Discomfort for a Code of Lighting**
R. G. Hopkinson B.SC. (ENG.) PH.D. M.I.E.E. (FELLOW)

139 **Technical Discussion Sessions at the 1960 Summer Meeting**

148 **Additions to the List of Members**

The opinions expressed by authors and contributors to discussions are those of the individuals concerned and are not necessarily those of the Society

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A Survey of Drawing Office Lighting Requirements

By J. B. COLLINS, B.Sc. (Eng.), A.M.I.E.E., (*Fellow*),
and F. J. LANGDON, B.A., D.Phil.

Summary

The requirements for lighting for draughtsmen were studied by a survey in ten different offices by questionnaire and interview. Independently, physical and subjective appraisals of the lighting and visual environments were carried out and the results were compared with the draughtsmen's reactions. From their reactions to the different kinds of lighting experienced, recommendations have been deduced for both daylighting and artificial lighting to achieve the most satisfactory conditions. For offices with a depth to accommodate more than four boards, or without double side daylighting, some top lighting in daytime is generally advisable. At night satisfactory conditions are most easily obtained by a moderately high level of general lighting of comfortable quality, supplemented by local lighting on the boards. If these latter are to be dispensed with, special attention to the shadowless quality of the lighting, brightness distribution in the environment, and elimination of reflected glare, is essential.

(1) Introduction

The present study formed part of a user survey dealing with the design requirements of drawing offices. In view of the fact that lighting is considered an important feature of the office environment, a considerable proportion of the survey was devoted to studying draughtsmen's attitudes to various methods of natural and artificial lighting. A particular object of the study was to compare the attitudes of draughtsmen toward fluorescent lighting, as opposed to incandescent lighting, and to general lighting as against local lighting. However, it was realised at an early stage in the work that there are so many factors influencing attitudes to any one form of lighting that these questions could only be answered within the framework of a more general study. In consequence, the survey was designed to give as complete a picture as possible of the environment and of the attitudes and responses of the draughtsmen who worked in it. It was also thought to be of value to discover what are the effects of varying standards and techniques of lighting in terms of the reactions of those who have to work under it. In particular there has hitherto been little evidence as to how far comfort aspects of lighting affect the user.

(2) The Sample

It was decided that the offices studied should be representative of current practice rather than outstanding examples of modern design, and ten offices were therefore chosen which, while possessing different systems of artificial lighting, covered the range of private and government employment with varying types of work, and included modern and older buildings. Table 1 gives details of the size and type of building, the type of work and the status of the employer. Day and night pictures of the offices studied are given in Appendix 3.

In order to compare results for offices using one system of lighting with those for offices using another, the sample has to be divided into groups representative of these systems. This introduces the possibility that there may be other differences among the offices or their occupants which would tend to vitiate any conclusions drawn from the comparisons. The characteristics of the populations were therefore studied to discover the extent of within-sample variation of features such as age, status, job-attitude, etc. Although systematic within-sample variations were revealed, they did not correspond with the comparison groups, nor were they sufficient to prevent the population being treated as a homogeneous one.

(3) Method of Survey

Each office was visited and the staff were interviewed. Each draughtsman completed a questionnaire dealing with (*a*) nature of work and job attitudes; (*b*) general appraisal of office amenities; (*c*) layout and equipment; (*d*) natural and artificial lighting. In addition to the written questionnaire, roughly 20 per cent of draughtsmen were interviewed privately, and informal interviews held with supervisors and management representatives. The survey covered only draughtsmen,

The authors are with the Building Research Station of the Department of Scientific and Industrial Research. The manuscript of the paper was first received on October 9, 1959, and in final form on November 9, 1959. The paper was presented at a meeting of the Society held in London on December 8, 1959.

Table 1

Offices used as sample in survey

No.	Employer	Type of Work	Building	No. of Staff	General Lighting	Local Lighting	Floor Area sq. ft.	Illustrated in Fig. Nos.
1	Private	Aircraft components	Single storey	48	Tungsten	Adjustable board lamps	4,048	1 & 2
2	Private	Handling plant	New, two-storey	52	Fluorescent	None	4,160	3 & 4
3	Private	Rolling mill plant	New, two-storey	51	Fluorescent	None	4,794	5 & 6
4	Private	Rolling mill plant	Old, three-storey	28	Fluorescent	None	1,904	7 & 8
5	Government Department	Telephone components	Old, multi-storey	21	Fluorescent	Adjustable board lamps	1,260	9 & 10
6	Government Department	Telephone equipment	Old, multi-storey	22	Tungsten	Adjustable board lamps	1,276	11 & 12
7	Government Department	Public buildings	New, multi-storey	19	Fluorescent	None	1,691	13 & 14
8	Government Department	Civil engineering structures	New, multi-storey	27	Tungsten	Adjustable board lamps	2,295	15 & 16
9	Government Department	Heating and ventilation	New, multi-storey	32	Fluorescent	Adjustable board lamps	2,268	17 & 18
10	Government Department	Production of maps	Modern huts	38	Tungsten	Adjustable board lamps	2,128	19 & 20

it being considered that tracers carried out work with different requirements and that their work should be dealt with separately rather than within the present survey.

A large amount of detailed information was obtained from the survey and it is only possible here to present a brief outline of some of the main conclusions.

(4) Appraisal of Lighting Conditions

Natural and artificial lighting conditions in each office were assessed by a lighting survey team, independently of the user survey. Illumination values or daylight factors were measured at different positions on a representative sample of drawing boards, and field brightnesses measured from a sample of working positions. From different positions within the offices, photographic records were made and processed under controlled conditions, to provide a permanent record of prevailing brightness distributions. Finally, colours of the main interior surfaces were recorded with the aid of Munsell value cards, and where possible these observations were supplemented by colour photographs.

Subjective ratings of glare, general comfort, gloominess, hardness of shadows, etc., were made by a member of the lighting survey team, over and above the objective measures applied.

The physical and subjective data thus obtained were compared, at a later stage in the survey, with the information derived from the user survey.

(5) Activity Sample

Work such as mechanical drawing is commonly assumed to constitute a somewhat prolonged and exacting visual task. It is therefore useful to know in quantitative terms what such a task amounts to, and also what variations exist between different offices, types of work or grade of employee.

To this end, a simple activity sample was carried out in six of the offices visited. The draughtsman's time was divided into four categories, based on earlier observation. These were: (*a*) drawing proper; (*b*) work other than drawing, such as calculations and notes; (*c*) consultation, discussion or telephoning; (*d*) visits to other parts of the office. In the six offices studied the overall pattern of activity was very similar, although the proportion of time spent in the different activities varied appreciably from grade to grade.

It will be seen from Table 2 that on the average, less than one third of a draughtsman's time was

spent in drawing, with about the same proportion of time spent away from the board altogether. In completing the questionnaire, draughtsmen had themselves estimated how they divided their time, and it is interesting to note that in every case the time spent on drawing was over-estimated, averaging 42 per cent against the measured 29 per cent.

The fact that only a small proportion of the time is spent on the drawing task in no way lessens the importance of designing the best practical lighting for this task, but it does point to the need to design an environment suited to a number of activities, such as consultation of reference data, filing, conferences, and so on, which take place in all parts of the office.

(6) Results of User Survey

Replies to the questionnaire were tabulated by means of punched cards and analysed in conjunction with recorded evidence from the interviews. This data was not passed to the lighting survey team until its statistical analysis was completed and conclusions had been drawn from it.

Replies to a number of questions were tabulated quantitatively and rendered as percentages, while others were weighted on a multiple choice scale to produce overall ratings. The first type of treatment, weighted for factors such as job attitude, etc., yielded indices of satisfaction with different features, while the second type gave rating scales for similar features derived from different questions. Checks were made for consistency and significance, and detailed analyses carried through for different offices with variables of age and grade.

(6.1) Attitudes to daylighting

It is possible to arrive at conclusions about the success of the various methods of daylighting studied by considering the rank order of satisfaction given by the users of each office, together with the reactions on brightness and glare, and study the way in which various characteristics of the daylighting affect the users' reactions in these respects. It should, however, be borne in mind that the comparisons between one office and another have not been made by those working in them. The offices can only be compared by the degree of satisfaction which those working in each of them express with their arrangements.

Respondents were asked, among other things, whether they could see clearly in daytime, by daylight alone or with supplementary illumination, whether their office was bright enough, the extent of supplementary illumination needed in winter and summer, and the degree to which they suffered from daylight glare. These questions were not made too precise in form, since it is essential that the respondent should be able to relate them to his familiar experience and answer by selecting a pre-coded statement which most nearly expresses his views.

Table 3 summarises replies to questions dealing with brightness and visual comfort for individual offices ranked in order of "satisfaction." The table also gives objective values of illumination or daylight factor as measured in each office.

A number of specific points arising from the comparison of different systems of daylighting are discussed in detail in Appendix 1. If the results shown in Table 3 are collated with the data of Table 1 it will be seen that the main features of the offices with high satisfaction scores are that they are of such a shape and size that the daylight may penetrate evenly to all parts of the room, by virtue of multi-sided lighting with unobstructed horizons, or lighting from roof glazing.

It will be seen from Table 3 that the measured or estimated amounts of daylight illumination do not correspond very closely with respondents' ratings. An internal check on the distribution of replies for consistency suggests that respondents' estimates are a more reliable guide to quality of daylighting than the physical measures of quantity, and it would seem that many more variables than

Table 2

Proportion of time given to different activities, for three grades in six drawing offices

Type of Work	Senior %	Basic Grade %	Junior %	Average Overall %
Drawing	19	29	37	29
Calculation	31	30	30	30
Consultation	15	16	10	13
Absence from board	35	25	23	28

Table 3

Offices in rank order of satisfaction with details of daylighting and users' comfort responses

Rank Order	Office No.	Percentage Score	Roof Lighting	Windows	Ceiling Height	D.F. Range %	Percentage answers on brightness of daylighting			Glare Comfort % Score†
							Too bright	Just right	Not bright enough	
1	1	93	N. light	Small single side	12′ to eaves	5-8	0	92	8	100
2	7	89.5	None	Medium mainly 3 sides	9′ 6″	0.5-8	0	100	0	100
3	4	85	Strip in E pitch	Small	9′ 6″ to eaves	4-14	0	93	7	82
4	2	75	None	Large N. side	11′	0.5-25	2.5	88	9.5	81
5	3	74	Small screened N. lights	Large 3 sides	10′ 2″	1-15*	4	70	16	78
6	8	68	None	Medium mainly 3 sides	9′ 6″	4 min.	0	68	32	76
7	10	45	Small skylights	Small	8′ 3″ to eaves	4-12*	0	12	88	90
8	6	43	None	Medium single side	10′ 6″	1 min.	4.5	36.5	59	8
9	9	28	None	Medium 1 or 3 sides	9′ 6″	0.75 min.	—	—	—	—
10	5	25	None	Large but obstructed, single sided	10′ 6″	1	5	19	76	91

* Estimated from Sky Factor.

† Based on frequency of complaints of glare. 100% corresponds to no complaints. (See Table 12, Appendix 1.)

measured quantity of illumination are involved in producing a verdict on office lighting. It can, however, be concluded from the ranking of the offices in the table that daylighting should be diffused as evenly as possible; that is to say, it should come from more than one direction and should not throw heavy shadows.

Only a small proportion of respondents complained of glare as such, the majority opting for the statement "about average." This may in part be due to glare not being explicitly recognised, and again, to the tolerance of some glare as unavoidable, and therefore within the pattern of expectation. The subject of glare was raised repeatedly by the investigators during interviews. Nevertheless, relatively few respondents mentioned it, even with prompting.

Unless daylight is evenly distributed throughout the room, preferably by means of roof lighting where possible, the parts of the office nearest the windows will appear too bright by contrast when viewed from the dimmest areas. Similarly, some respondents pointed out that the external scene viewed through large glazed areas appeared too bright from deep within the room.

The need for sunblinds or window curtains would appear to relate to the same point, for although 17 per cent of respondents claimed that they needed blinds, and another 40 per cent claimed to need them at some time or other, only 17 persons, or 5 per cent of the total sample, also claimed to be able to work by daylight alone. The majority of those claiming to need blinds were therefore not situated in brightly lit areas, and their needs may be presumed to arise from the distraction caused by the distant view of sky and bright areas in the distance.

Apart from the problem of glare, an office deep

enough to hold three or four lines of drawing boards, but lit from one side only, will need supplementary artificial lighting for most of the day, even in sunny weather. This was the case in office No. 5, a very poorly lit room. Office No. 2 on the other hand, a modern purpose-designed building, was designed with this intention, and draughtsmen working on the line farthest from the windows relied on the very high level of general lighting from the overhead fluorescent tubes, which remained switched on for most of the day.

Although most of the offices studied reported satisfactory daylighting, in the less good offices (and particularly in office No. 10) workers whose boards stood alongside window piers received insufficient light. It is evident that rooms with wide piers seriously reduce flexibility in layout, and waste valuable space, through inferior daylighting at many positions.

The evidence therefore suggests that the best way to light an office is by roof lighting, and it indicates the shortcomings of large windows for this purpose. As regards the level of daylighting, a 5 per cent daylight factor appears from the survey to be a reasonable minimum to enable the great majority of the occupants to work for most of the day without resorting to artificial light.

(6.2) Attitudes to artificial lighting

The sample of offices studied may be divided into two groups, each of which consists of two sub-groups. In the first group, offices using general lighting may be compared with others using general lighting supplemented by local adjustable lamps. In the second group, offices using fluorescent lighting (hot cathode except in the case of office No. 2) may be compared with others using incandescent lighting. These groupings are, of course, to some extent arbitrary, since in practice these systems are variously combined. Thus of the offices using local lighting, Nos. 1 and 10 rely almost wholly on lamps at the drawing board, while others obtain a far greater contribution from the overhead sources. Again, some of the offices with fluorescent lighting are equipped with lamps at the board, others are not; some use louvred fittings while others employ open trough ceiling fittings.

It is therefore simplest to begin by ranking replies to questions on artificial lighting for all offices, irrespective of the system of illumination employed, in order to summarise the attitudes of their occupants and relate them to differences in lighting techniques.

The derivation of the satisfaction index for lighting is discussed in Appendix 2, where it is also compared with similar indices for other office amenities.

Table 4 lists offices in ranked order of user satisfaction with artificial lighting and also gives details of the installations. There appears, at first sight, little relation between the average illumination level and the index of satisfaction. However, after allowance has been made for the effects of local lighting and differences in the design features of the installations, the respondents' ratings can be interpreted in terms of design requirements. Where only general lighting is employed, the fluorescent installations alone gave enough light (though this is not to say that sufficient light could not be obtained from incandescent lighting were this intended), and nothing lower than 25-30 lm/ft^2 appeared to give reasonable satisfaction. Where local lighting was employed, the adjustable lamp provided 50-150 lm/ft^2 over a limited area at the working plane, and gave fair satisfaction.

For a higher level of satisfaction, more adequate general illumination is necessary. What the respondent tends to overlook when assessing the adequacy of his lighting, is that good lighting is required not merely at the drawing board, but throughout the office. As was indicated by the results of work study, only one third of the draughtsman's time is spent in drawing, and nearly a third of his time is spent at activities away from the board. This fact must be taken into account when making recommendations for suitable levels of illumination.

For the present however it is possible to begin by grouping the offices according to the respondents' ratings, and when this is done, the values given in Table 4 divide roughly into three groups as follows :—

Group 1. Satisfaction greater than 75 per cent. Offices 1, 2 and 3.

Well diffused "shadowless" general lighting, from carefully designed fluorescent fittings in the case of offices 2 and 3, and from diffuser/reflector type filament fittings plus local lamps in office No. 1.

Group 2. Satisfaction 66-68 per cent. Offices 7, 8 and 9.

Offices 7 and 9 are lit approximately to the I.E.S. recommended level by general fluorescent lighting only, although in No. 9 the draughtsmen have endeavoured to retain their local lamps. In No. 8, they only obtain adequate light by the use of local lamps, but, being so provided for, appear satisfied with the level of general lighting.

Table 4

Ten offices ranked for satisfaction with lighting giving mean illumination values for general lighting only

Office No.	Satisfaction Index	Average Level of Illumination Lm/ft²	Source	Type of General Lighting Fitting	Approx. Mounting Height ft.	Local Lights	Proportion of Upward Light
1	82	11.5	Filament	Industrial metal diffusing reflectors with opal diffusing globe	11	Yes	Low
2	79	76.5	Fluorescent (hot and cold cathode warm white)	Overall ceiling lighting from asymmetric directional trough reflectors, lighting mainly from behind draughtsmen	11	No	—
3	76.5	26.5	Fluorescent (white 3,500°K)	B.R.S. louvred fittings	8½	No	High
9	68	30	Fluorescent (daylight)	Directional metal asymmetric reflector troughs mounted at left-hand side of boards plus louvred general lighting fittings	9	Yes	None
8	67.5	7.5	Filament	Opal globes with prismatic bottom dish	8	Yes	High
7	66.5	35	Fluorescent (daylight)	As No. 9	9	No	None
6	56	3.5	Filament	Few totally enclosed opal globes	8	Yes	High
4	55	26.5	Fluorescent (daylight)	Open diffusing metal industrial trough reflectors	9	No	Low
10	51.5	3	Filament	Few industrial metal diffusing reflectors	12½	Yes	None
5	43	19	Fluorescent (warm white)	Bare lamps	9	Yes	High

Group 3. Satisfaction below 60 per cent. Offices 4, 5, 6 and 10.

The general lighting of offices 6 and 10 is altogether inadequate, but local lamps are provided, and the general result is rated no worse than the harsh and glaring effect of open trough fluorescent fittings close to the board in No. 4. There remains office No. 5, which has bare fluorescent tubes suspended from the ceiling. The illumination given by these fittings is only two thirds of the recommended minimum value. Local lamps are provided but the discomfort caused by this crude system contributes to a low index of satisfaction.

The value of respondents' ratings is to show, not a precise comparison between different forms of lighting, but (when allowance is made for extraneous influences) the effect of the various features on the satisfaction or contentedness of the draughtsmen in each office, independently of the way in which they themselves recognise these features. Thus the paramount factor appears to be the elimination of hard shadows, and second to this comes absence of glare. The average level of illumination seems to be of less importance, particularly if local lamps are provided.

Where local lamps were not provided, the average general illumination was to the level recommended by the I.E.S. code or above. While the office with 76 lm/ft² ranked higher than the other office lit in a similar way, the results do not particularly stress the value of increasing illumination greatly above the recommended value, since an appreciable proportion of draughtsmen here expressed the opinion that the office was too brightly lit, and this particular office ranked high for glare discomfort (see section 6.5).

(6.3) General versus local lighting

The attitudes of draughtsmen using local lighting may be compared with those of draughtsmen using general lighting by aggregating scores for the two groups.

In attempting to draw conclusions from such a comparison however, it must be borne in mind that other factors were not constant for the two groups. Thus offices using general lighting tend to use fluorescent lighting, whereas it is more common to find incandescent lighting used in association with local lamps, and in this case, preferences for one or other type of source may confuse the issue. Furthermore, the offices using general lighting are mostly purpose-designed for this system and are generally more modern, so that satisfaction with the overall environment may tend to bias the draughtsman's views on lighting.

In view of these differences, it is perhaps not surprising that overall satisfaction was somewhat higher for offices lit by general lighting (67 per cent satisfaction) to a level of 41 lm/ft², than for offices relying on local lamps for the illumination of the boards, with a general illumination level of about 10 lm/ft² (60 per cent satisfaction). Furthermore, this appreciation parallelled very closely the average index of satisfaction with daylighting for the two groups of offices. On the other hand, the detailed analysis of answers to specific questions dealing with visibility, brightness and glare under artificial lighting given in Table 5 Indicates the difficulty of providing satisfactory lighting by the use of a general system alone.

It is interesting to note from Table 5 that although 93 per cent of those provided with local lighting enjoyed satisfactory vision at the board (13 per cent without using their local lamps), only 72 per cent of those with general lighting alone claimed to be able to see clearly, while 22 per cent thought they would if they had a local lamp. This suggests that if local lighting is to be obviated, the general lighting system must be very carefully designed, and in fact, the majority of those claiming to need a local lamp, but not possessing one, belonged to the old, non purpose-designed offices in the sample.

Replies to a direct question asking respondents whether or not they needed an adjustable lamp, presented a similar picture. Here again, as shown in Table 6, there remained 25 per cent of respondents in offices using general lighting only who claimed to need a local lamp. Moreover, quite apart from whether or not a local lamp was provided at the board, a frequent complaint against general lighting systems was that the

Table 5

Replies to three questions on artificial lighting for total sample, and two groups of offices, expressed as percentages

	General Lighting Users (Group 1) %	Local Lighting Users (Group 2) %	Total Sample %
Can see clearly at board :			
1 By general lighting ...	72	13	42
2 With local lamp	22	80	52
3 Not at all ...	5	3	3.5
4 No opinion ...	1	3	2.5
Brightness at night:			
1 Too bright ...	16	1	8
2 Just right ...	63.5	44	53.5
3 Not bright enough ...	18.5	53.5	36.5
4 No opinion ...	2	2	2
Glare at night :			
1 Glaring	29.5	8.5	18.5
2 About average...	55.5	64.5	60
3 Restful to the eyes	8	8	8
4 No opinion ...	7.5	20.5	14
Sample No. ...	150	188	338

Table 6

Need for adjustable lighting, compared for two groups of offices, using general and local lighting, expressed as percentages

Do you need an adjustable lamp ?	General Lighting Users, Group 1	Local Lighting Users, Group 2
	%	%
Never	43.5	1.5
Rarely	31.5	24.5
Frequently	17.5	55.5
Always	7.5	18.5

fixtures could not be adjusted relative to the boards, or were located conveniently to supply outlets rather than in relation to the office layout.

Thus it would seem that in the sample of offices studied, the attempt to obviate local adjustable lamps had not been altogether successful, when account is taken of the number of draughtsmen who remained not entirely satisfied by general lighting. At the same time, it must be recognised that while 63 per cent of occupants of offices using general lighting thought their office lighting "just right" in brightness, only 44 per cent of those in offices using local lighting were of the same opinion. The majority (53 per cent) of these latter regarded their offices as "not bright enough," so that, in line with the overall satisfaction scores, it would seem that general lighting was more successful in illuminating the offices to a satisfactory brightness level.

It is clearly somewhat difficult to judge between the respective merits of these two systems, especially when it is remembered that the psychology and outlook of the draughtsman must also be taken into account. Draughtsmen are in many ways technical craftsmen and their outlook is to a considerable degree coloured by tradition. They have a strong sense of working community and professionalism, and, though they may in their daily work be concerned with innovation, in all that pertains to their surroundings they look to the past rather than to the future.

Their outlook towards the kind of lighting provided is therefore strongly orientated towards the well-known and long established methods, such as ordinary incandescent lighting with an adjustable lamp at the board. Such an arrangement gives them some control over their surroundings, enables them to tolerate lighting conditions which would otherwise be unacceptable, and to make necessary adjustments, eliminate shadows, and so on. In addition, they can eliminate, if they wish, awareness of what is happening further away and concentrate on the task at hand. Finally, the light emitted by the shaded local lamp is warm and friendly; it is a familiar and traditional part of the work environment.

As against this, general lighting is still comparatively new. It is distant, often harsher and less intimate. It cannot be controlled by an individual draughtsman, and if badly designed, places him in a frustrating environment. He is also made more sharply aware of his general surroundings and may feel less able to concentrate fully on his work.

If general lighting does not offer solid and tangible advantages over local lighting, it may be regarded simply as a loss of control over one more aspect of the environment, and will not be favourably received, particularly by the older, more traditionally minded men. It must therefore give the draughtsmen adequate light, evenly distributed and free from glare, and must be free from unpleasant shadows, flicker and harsh colour renderings.

To do all this a general lighting system must be designed extremely critically, and when it is remembered that little or no adjustment is possible, and that mistakes are difficult and expensive to rectify, it is perhaps not surprising that general lighting as studied in the sample offices failed to show significantly superior results as compared with local lighting, even though the overall environment was illuminated to a more adequate level.

In conclusion, it must be pointed out that results from a number of laboratory studies of vision and lighting suggest that visual requirements may be more easily satisfied by means of local, rather than by general artificial lighting. Thus the work of Lythgoe[1], and more recently, Stevens and Foxell [2, 3] has shown that visual acuity is greatest when the task brightness is equal to or slightly above that of the surround, while Hopkinson[4] has shown that visual comfort is greatest when task brightness is greater than the immediate surround brightness, which in its turn should be greater than the general surround brightness. It is also well known that vision tends to be directed toward the brightest part of the visual field, as has recently been demonstrated experimentally by Hopkinson and Longmore[5]. It would therefore be expected that visual comfort and performance would be around the optimum levels if the illumination of the immediate task were achieved by good general lighting supplemented by a local adjustable source to give a higher local level of illumination.

(6.4) Incandescent and fluorescent lighting

As already pointed out, the grouping of offices into those with fluorescent and incandescent tungsten filament lighting overlaps to some extent with the grouping made in comparing general and local lighting. As can be deduced from Table 1, only two offices, Nos. 5 and 9, move into the opposing group, Group A being otherwise identical with Group 1, since the majority of offices using general lighting also use fluorescent tubes to provide it.

As many of the factors discussed in the preceding section govern satisfaction with fluorescent lighting

Table 7

Attitudes to fluorescent lighting for total sample, and users of fluorescent and incandescent lighting, expressed as percentages

Attitude to fluorescent lighting	Group A Fluorescent users %	Group B Incandescent users %	Total Sample %
1. Unqualified approval ...	32.5	12.5	24
2. Qualified approval ...	38	25	33
3. Neutral ...	8	37	21
4. Qualified disapproval	12	12.5	12.5
5. Unqualified disapproval	9.5	13	11

when it is compared with incandescent lighting, it is not surprising that the two sets of analyses follow a similar pattern. Fluorescent lighting can provide a high level of illumination over large areas with freedom from heavy shadows, though great care has to be exercised to avoid discomfort from glare, or (less obviously) incorrect balance of brightnesses.

However, in addition to assessing satisfaction with lighting, the survey was concerned to evaluate respondents' attitudes to fluorescent lighting as such. Table 7 presents this information in simplified form, for the total sample, and for users of the two types of lighting. Replies to questions are given as percentages distributed over the scale of five possible attitudes, ranging from unqualified approval to unqualified disapproval. It will be seen that although those using fluorescent lighting are more in favour of it than those not doing so, there is no fundamental difference in attitudes, as is indicated by the similarity between degrees of disapproval.

The main attitude to fluorescent lighting is favourable, over 70 per cent approval, with or without further qualifications, in the case of respondents using it, supported by nearly 40 per cent of those not using it. Opposition is from only 25 per cent and 20 per cent for these two groups, the main attitude for the non-users being one of neutrality.

Analysing the main arguments for and against fluorescent lighting, the comments made in questionnaires and interviews are reduced to eleven categories. Table 8 presents these in comparative form. The most frequently mentioned point in its favour is evenness of distribution, comments on intensity appearing only as objections. Both users and non-users refer to glare as an objection, while an interesting feature is the difference in frequency between the two groups in complaining of flicker. This suggests that flicker is more often anticipated than actually experienced and is possibly related more to the installations of ten years ago than to those of the present.

If the attitudes of the two groups are analysed by age groups, as presented in Table 9, some interesting differences emerge. It seems that in

Table 8

Comments on fluorescent lighting by draughtsmen using (1) fluorescent and (2) incandescent lighting, tabulated by frequency of mention, expressed as percentage of total comment

Good Features	Percentage of Approvers		Bad Features	Percentage of Disapprovers	
	Group A (Fluorescent users)	Group B (Incandescent users)		Group A (Fluorescent users)	Group B (Incandescent users)
Even distribution	26	31	Uneven distribution	1	0
Freedom from glare	3.5	7	Glaring	19.5	19
Shadow free	22	13	Bad shadows	7	7
Good natural light	8	9	Flickers	12	27
Better than tungsten	11	8	Too bright and harsh	6	3
All other good points	29.5	32	Not adjustable	14	13
			Bad for the eyes	11.5	16
			Other bad points	29	15

Table 9

Attitudes to fluorescent lighting of users and non-users tabulated by age and expressed as percentages

Attitude	(1) Using Fluorescent Lighting				
			Age		
	16-25	26-35	36-45	46-55	Over 55
1. Unqualified approval	31.5	30.5	30.0	37.5	50
2. Qualified approval	36.8	46.5	33.0	31.0	25.0
3. Neutral	8.8	5.5	16.5	6.0	0
4. Qualified disapproval	15.8	9.0	10.0	12.5	16.5
5. Unqualified disapproval	7.0	9.0	10.0	12.5	8.5
	(2) Using Incandescent Lighting				
1. Unqualified approval	26.0	16.3	7.5	0	0
2. Qualified approval	22.0	27.0	31.5	23.0	0
3. Neutral	22.0	33.5	39.0	31.0	82.0
4. Qualified disapproval	22.0	12.5	10.0	7.5	9.0
5. Unqualified disapproval	8.0	10.5	12.0	38.5	9.0

the offices using fluorescent lighting, the older men are more strongly in favour of it than are the younger men, while in the offices using incandescent lighting, the reverse is the case, though the fall away from a favourable attitude is not accompanied by a rise in the numbers opposed to it, but merely by an increase of neutral opinions. Thus the general picture presented by the data is that although older workers tend to view fluorescent lighting less favourably where they have not experienced it, they have come to accept it more favourably than younger workers where it has been installed.

Detailed analysis of replies failed to relate complaints of headaches and visual difficulties among different age groups, either for the total sample or for particular groupings of offices. It must be concluded, either that the questions were insufficiently sensitive to measure such effects, or that in relation to the needs of the task, lighting was not poor enough to produce differences on this score. There are indications, moreover, that complaints of headache and fatigue are related more closely to ventilation and to mental strains imposed by the job than they are to lighting.

It may therefore be concluded that where fluorescent lighting had been installed with care it was successful, the majority of users finding it satisfactory. Even where it had been poorly arranged in old and ill-adapted offices, support for it was quite strong, since it was almost always an improvement on the previous installation.

(6.5) The achievement of visual comfort with artificial lighting

The experienced observers responsible for the lighting survey assessed the visual comfort levels in each office using their previous experience in laboratory and field studies. The users of the installations were not expected to be able to rate their conditions comparatively, though it has been found that unskilled subjects' opinions on "brightness" and "glare" of an installation (the latter are much rarer than complaints of "too bright" or "too much light") usually bear some relation to comfort conditions as an aspect of the environment brightness pattern.

As it was not possible to assemble a team of experienced observers to visit each of the offices studied, the assessment of comfort was made by the same member of the team for each office in the sample. The data given in Table 10 represent his assessments, made at a number of positions in each office, for visual comfort when the interior is viewed upon raising the eyes from the drawing board. Column 3 gives the descriptive rating and Column 4 relates this to the B.R.S. glare criteria (specified in Table 11), also giving the comments on brightness balance for the complete environment.

Table 10 also gives users' assessments derived as percentages from their answers to questions on "brightness" and "glare" (100 per cent comfort rating corresponds to no glare). Offices are ranked in order of overall satisfaction (satisfaction index) though the last column of the users' assessment section gives the ranked order for visual comfort (based on absence of complaints of glare).

The photographic records were used to calculate the glare constant relative to one particular point of view, by relating a measurement of average density to the spot brightness measurements made on site to obtain the background brightness. The areas of the light sources in the photographs were planimetered, and a correction made by studying the plans to include all the sources visible within an angle of 45 degrees to the normal line of sight. These data, together with the brightness of the

Table 10

Summary of quality assessment of general lighting installations

Experienced Observer's Assessment					Users' Assessment					Calculated Glare	
					Percentage Responses on Brightness			Glare			
Office No.	Shadowing	Comfort Criterion for General Lighting	Approximate Corresponding B.R.S. Glare Criterion	Balance of Brightness	Too bright	Just right	Not bright enough	Comfort rating %	Rank order	Glare Factor	Criterion
1	Not too dense	No perceptible glare	D	Roof too dark	2	71	25	89	3	66	B
2	Little shadow	No glare from lighting	less than D	Slight glare from paper	29	71	0	60	7	5.3	D+
3	Soft shadows	Perceptible discomfort	C	Fittings rather too bright	4	76	14	84	4	202	B−
9	Rather hard shadows	Comfortable	D	Uneven illumination	Questions not included in pilot study						
8	—	Slight glare	B/C	Stimulation and some distraction	0	46	54	71	6	117	B+
7	Some hard shadows	Comfortable	Less than D	Sharp variations in illumination	16	52	32	48	8	32	C
6	—	Uncomfortable	A/B	Generally gloomy	0	23	77	100	1	88	B/C
4	Some heavy shadows	Perceptible glare	C	Ceiling not too gloomy	14	32	54	25	9	33	C
10	—	No glare from general lighting	—	Gloomy	0	16	79	90	2	35	C
5	—	Uncomfortable	C to B*	Satisfactory apart from bare lamps	0	52	48	75	5	235	B−

* According to position.

fittings (measured on site) were used to calculate the glare factor using the B.R.S. formula.

$$G = \frac{\omega^{0.8} B_s^{1.6}}{B_b}$$

where ω is the total solid angle subtended by all the sources, B_s the source brightness and B_b the background brightness.

The values of the glare constant and their

Table 11
B.R.S. Glare Criteria

Glare Criteria	Degree of Glare
More than A	Intolerable discomfort
A	Just intolerable
A/B	Uncomfortable
B	Just uncomfortable
B/C	Distracting but not uncomfortable
C	Just acceptable
C/D	Acceptable but not imperceptible
D	Just imperceptible
Less than D	No glare

equivalent in glare criteria are given in the last two columns of Table 10. It will be seen that the individual observer generally rated the installations at from one half to one criterion less glaring than given by the formula, although in one case he differed by two criteria (there was some difficulty in this installation in assessing the correct average brightness of the two-part lighting fitting), and in one other case he rated the installation one criterion more glaring than would have been expected from the calculations.

No correlation tests have been made between the various assessments, but from inspection it would appear that while the individual observers' estimates would correlate well with measured glare factor, the users' assessments are not correlated to any great extent with the degree of glare from the general lighting. With the possible exception of those in offices 2 and 4, the draughtsmen appear mainly concerned with the effect of the intrusion of the surroundings on their work.

It will be noted that the three offices ranked with lowest complaints of glare, quite apart from suitability in other aspects, are those with local lighting and low levels of general (filament) illumination. The B.R.S. type fitting gives rise to less complaints than one would expect at low mounting height, while the overall directional ceiling lighting installation is found less comfortable than would have been expected. It can only be concluded that in the latter office the glare from the strongly illuminated drawing paper and the rather dark apparent ceiling and dark furniture, which were noted by the experienced observers, lead to an unsatisfactory environment brightness pattern which is more worrying to those working in the office for a long period than might be supposed from short term observations. This is quite strong confirmation of the opinions of the experienced observers that, good though this lighting system is in most respects, the balance of brightness between the work and surroundings, particularly the ceiling, could be improved with some advantage.

The offices with the highest number of complaints of glare are found among those not using local lights and do not include the installation with bare fluorescent lamps, where the use of local lights seems to alleviate appreciably the discomfort which might have been expected.

(6.6) Colour treatment

It was found that in many cases variations in expressed satisfaction with lighting tallied with the amount of attention that had been given to functional design of the colour treatments. It cannot be too strongly emphasised that colour finishes of walls and furniture largely determine the visual appearance of the surroundings. Carefully planned colour treatment helps to achieve a correct balance of the brightnesses making up the visual field, and also to produce the appropriate atmosphere and degree of stimulation. These factors have been discussed elsewhere[9] and it must suffice here to reaffirm that no scheme of natural or artificial lighting can be wholly successful unless thought is given to the design of the colour scheme.

(7) Conclusions

Before drawing conclusions from the results of this study, some note must be taken of the way in which draughtsmen regard lighting as an aspect, among others, of their environment. Thus, when completing a check list of praise or criticism covering 21 items, it is interesting to note that lighting was never placed first in either category. Hence, although all draughtsmen agreed that lighting was extremely important, few regarded it as the most important feature. Most draughtsmen stressed the need for good ventilation and adequate space. It is of course possible that these rankings indicate that the quality of lighting in all the offices studied was considered adequate, so that its importance was not strongly felt. This, however, seems unlikely in view of the actual ratings given for satisfaction with lighting. It is more probable that the importance of lighting is in fact under-estimated, because inadequacies in features such as ventilation, even in modern drawing offices, are often more predominant in attracting attention.

In trying to use the conclusions of the present study to answer the questions with which a lighting

engineer is faced, it is important to remember that it is a survey of draughtsmen's opinion related to measurements and appraisals of outside observers. Although the findings are in agreement with the results of fundamental lighting studies, it is not a direct experimental investigation. Nonetheless, if used in conjunction with the available data on lighting, its conclusions could be used as the basis of design for any new drawing office, though it would clearly be an advantage to be able to apply them to an experimental building to obtain more precise and detailed information.

The conclusions may be summarised as follows :

(7.1) Daylighting

Draughtsmen carry out 90 per cent of their work during daylight hours, so that good natural lighting is a prime requirement for a drawing office. To give satisfaction to the occupants, daylight must be evenly distributed through the office, and must arrive at the working plane through a wide angle. A daylight factor of 5 per cent would seem a reasonable design minimum. Ceilings should be as light as possible to ensure maximum diffusion of light. If brightness levels fall off sharply in parts of the room distant from the windows, high contrast ratios will lead to complaints of glare from occupants working in these areas. While those working close to windows often have enough direct illumination to offset discomfort from a bright sky, draughtsmen working in the centre of the room will tend to have bright areas in their field of view, producing high contrast with their immediate environment, especially if the horizon is unobstructed. Any attempt to raise the illumination level in parts of the room by increasing the size of the windows can only increase glare at the same time. The solution to such a problem is therefore to provide roof lighting, though this may result in excessive solar-heat gain. To avoid this, either north lights or well-screened monitors should be used.

Drawing offices in multi-storey buildings (other than on the top floor) can only receive adequate daylighting in comfort, even from double side lighting, if they are fairly narrow, having a width to accommodate not more than four boards if the ceiling height is not more than 10 feet. There is evidence that the use of large and high windows to achieve penetration of daylight in a deep office produces noticeable discomfort. To obtain satisfactory visual conditions in wider offices without roof lighting, it is necessary to consider the provision of permanent supplementary artificial lighting in the darker parts. Hopkinson and Longmore([7]) have pointed out that quite high levels of supplementary artificial illumination are required under these circumstances, and their paper gives data enabling appropriate values to be calculated.

Windows should not be larger than is necessary to obtain the required level of illumination, and those likely to admit direct sunlight or give views of very bright exterior surfaces should be provided with curtains, or preferably with louvre blinds. The windows, however, should not be narrow with large areas of brickwork between them, but should be as wide as possible and restricted in height so that daylighting will be uniform along the length of the office. Even if the main lighting is from above, some view windows should always be provided.

(7.2) Artificial lighting: general and local

The respondents' ratings of their lighting failed to show that the results achieved by means of general lighting were significantly better than those achieved by local lighting. One reason for this may be that the offices selected for study were representative of current practice rather than outstanding examples of these two systems, so that even in the most modern installations some deficiencies were still evident.

Overall satisfaction with lighting appeared to be governed by the care taken over the design of the lighting installation rather than by the type of system employed.

If the overall index of satisfaction is studied in conjunction with the reports of clear vision at the board and absence of complaints of glare or of the office appearing "too bright at night," it becomes evident that the draughtsman's requirements are best satisfied by providing background illumination (at a level of about 25-30 lm/ft^2) designed to give a high standard of comfort, and supplementing this with local lighting under the control of the draughtsman. The background lighting will be most comfortable if it comes from a large number of low brightness fittings well above the line of sight, throwing at least 25 per cent of the light upwards for redistribution by the ceiling. To the extent that this was achieved in office No. 1, this gave the highest index of satisfaction of all the offices studied. Fittings which could be used to achieve such results are those which meet the Ministry of Education Regulations for classroom lighting, which may be used as a guide in respect of brightness, cut-off angle, and proportion of upward light.

(7.3) Fluorescent lighting

There seems to be no reason why the general lighting described should not be provided by

fluorescent lamps, and the illumination levels suggested can easily be attained by this means, though it is not easy to design a fitting to give adequate sideways distribution of light at a mounting height lower than 10 ft. The B.R.S. fitting would probably be successful even at low heights when employed in conjunction with local lamps, but it was found to be too bright below 10 ft. when used as the sole source of light.

The general attitude of draughtsmen appeared very favourable to fluorescent lighting, though less favourable to its use without adjustable lamps at the board. It is evident that these attitudes are still in process of change, and with experience of modern fittings fewer complaints of flicker, multiple shadows, etc., are forthcoming. It is mainly among older draughtsmen that criticisms are met with, though these often relate to experience of early fluorescent installations. With more experience of present-day installations these older men become more favourably inclined to fluorescent lighting.

(7.4) Illumination levels

While mere intensity of illumination is not an adequate guide to the suitability of an installation, it would seem that general illumination should be as stated above, i.e. not less than 25-30 lm/ft², where local lamps are employed. The reason for recommending this particular level is to ensure a suitable brightness grading between the task area and the surroundings, and also to provide an adequately high illumination for tasks such as reference to tables or drawings away from local lights. If local lights are to be avoided, a higher level of general lighting appears desirable, and 50-100 lm/ft² would seem appropriate. It should be borne in mind that within the restricted area lit by an adjustable lamp, values of 100 lm/ft² and more are easily obtained. Since the removal of this adjustable lamp prevents the draughtsman from arranging his lighting to suit his own convenience, it is essential that this loss is made good by general lighting superior in quality (if not in quantity) to the local lamp it has replaced.

When deciding on the illumination to be provided, in conjunction with the type of fitting, the designer might with profit bear in mind a recommendation of the Australian Lighting Standard([8]). This recommendation states that where there is any possibility that pencil lines on a drawing may reflect the brightness of the lamp or fitting at a specular angle, the illumination of the drawing board (measured in lumens per sq. ft. or foot-candles) should not be less than 12 times the luminance of the bright areas (measured in candelas per sq. in.). Thus if fluorescent lamps (which have a luminance of up to 6 cd/in²) are used in open trough fittings, an illumination of not less than 72 lm/ft² should be provided, unless the fittings can be so arranged that specular reflection can be avoided (e.g. by light reaching the board from behind the draughtsmen, or from the side). In addition, it should be noted that the recommended ratio is increased to 24 : 1 in the case of high gloss drawing surfaces such as tracing cloth.

(7.5) Installation design

Although fundamental studies tend to show that the best visual conditions are produced by general lighting supplemented with local lamps, the overall conclusions of the present survey indicate that by careful design, a fluorescent general lighting system employing directional ceiling reflectors, or well screened individual fittings giving plenty of upward illumination, can give satisfactory results. Such a solution undoubtedly lessens the overall problems of office design. For if the cost of fittings can be kept at a low figure, the greater flexibility in layout planning, more economical use of office space, lower current consumption, and higher general illumination levels available from fluorescent lighting, may outweigh the attractions of local tungsten filament lighting. At the same time, it needs to be emphasised that a system of fluorescent general lighting supplemented by adjustable local lamps presents fewer and less critical design problems than a purely general lighting system.

If local lighting must be dispensed with, it is essential that the general lighting be uniformly distributed, avoiding harsh shadows. If a luminous ceiling is intended, particular attention must be paid to the balance of luminance between the ceiling, the drawing paper and the general surroundings, which in these circumstances becomes critical. Pending further laboratory and field data for the luminance ratios of these three surfaces, suggested objective values are 7 : 10 : 1, respectively.

The present study has indicated very clearly the difficulties of obtaining comfortable lighting—as distinct from generous quantities of light—by means of general lighting alone. Thus in one office, otherwise well-lit to a high level of illumination, failure to achieve a satisfactory brightness balance between the drawing board and the general surroundings resulted in complaints of glare and over-brightness.

Linked with this, a further result of the study

has been to show that local lighting of drawing boards by means of general lighting fittings sited close over them is unsatisfactory, unless attention is devoted to avoiding visual discomfort or obtaining an appropriate brightness distribution over the general environment. Where adjustable local lamps are not provided, light must come from a number of overhead fittings to prevent hard shadows.

In conclusion, the present results indicate the limitations, both of conventional techniques for measuring and appraising lighting installations, and of user surveys as means of arriving at design data. Such methods can do little more than point to the key factors to which attention must be directed and indicate the failure or success of existing schemes. To result in precise design specifications, more direct methods need to be developed in conjunction with the existing data from fundamental lighting studies.

(8) Acknowledgments

The authors would like to acknowledge the co-operation of their colleagues in the collection and analysis of the data. They are also indebted to the management and personnel of the drawing offices studied, who so readily co-operated in the survey.

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Appendix 1

Responses to questions on daylight

Table 12 gives the answers to some of the questions on daylight analysed in percentage for staff grades over the whole sample, and Table 13 gives details of the responses on ability to work by daylight alone in winter and summer, for individual offices arranged in order of the overall satisfaction index.

Inspection of the tables shows that the great majority of respondents obtain more or less

Table 12

Questions on daylighting summarised for total sample and by grade

	Total %	Senior %	Basic %	Junior %
Clear vision at board :				
1. By daylight alone	71	78.5	69	57
2. By artificial light	27.5	20	30	41
Ability to work by daylight alone (winter) :				
1. Never	17	8	19	22
2. Few days... ...	21	16	21	25
3. Some days ...	27	30	25	28
4. Most days ...	26.5	30	28	23
5. Almost always ...	7	16	6	—
No opinion ...	1.5			
Ability to work by daylight alone (summer) :				
1. Never	8	1	8	13
2. Few days... ...	6	3	9	5
3. Some days ...	12.5	12	14	10
4. Most days ...	22	23	21	23
5. Nearly always ...	51	61	48	48
No opinion ...	0.5			
Estimated brightness of office by day :				
1. Too bright ...	3.5	3	4	1
2. Just right ...	66	72	67	51
3. Not bright enough	29	23	29	33
Glare in daytime :				
1. Glaring	8	16	6	4
2. About average ...	63	65	71	66
3. Restful to the eyes	9	19	5	6
No opinion ...	16	—	19	22

Table 13

Ten offices ranked for ability to work by daylight alone (winter and summer) arranged as a frequency table. Total Sample No.=338

Rank Order	Office No.	Never	Few Days	Some Days	Most Days	Nearly Always
1	1	—	7	10	39	43
2	7	5	3	23	29	39
3	4	3	9	21	20	41
4	2	9	9	22	25	34
5	3	8	12	21	27	31
6	8	8	18	17	23	34
7	10	19	24	28	17	11
8	6	25	27	21	22	4
9	9	17	39	23	17	2
10	5	62	16	19	2	—

satisfactory daylight. There is, however, some difference between different grades on this score. It will be seen that there is a constant tendency for senior draughtsmen to enjoy better daylighting than lower grades. When the seating plans of the offices were examined it was found that senior draughtsmen tended to choose positions near the windows—and this finding was reinforced by comments to this effect made by respondents in interviews—so that when related to the work study results it will be seen that those draughtsmen spending thé greatest amount of time in drawing receive the worst daylighting.

The efficacy of the various arrangements for daylighting may be compared by a detailed study of Table 3 of the paper, and some of the points which arise are discussed below.

The large windows on three sides of No. 3 do not seem as popular as might be expected and this is probably due to the responses of a group in a section which receives little benefit in direct light from the windows but suffers the disadvantage of being able to see rather a large area of sky, as well as to the complaints of a few people who find the large windows "too bright." Low ranking also seems to be given on account of the use of artificial lighting during the daytime. This may arise from having too much daylight or at any rate too large an area of sky visible. It is also significant that this office is ranked seventh in the responses on glare discomfort.

Lighting from windows on one side only without the addition of a substantial amount of roof lighting does not appear to be very satisfactory even when the office is only two boards deep, and as a substantial proportion of office No. 9 is of this form, this, as well as the high degree of obstruction to the windows by adjacent buildings, probably accounts for its low ranking. Number 8 is a similarly shaped office but on a higher floor of the same building and with less area of single side lighting, while No. 7 is on the top floor of the same building and has most of its drawing boards adjacent to windows. It is surprising that No. 7 ranks so much higher than No. 8 in the comfort scale and impression of brightness, but this may again be due to less work being carried out at positions away from the windows. The position of No. 2 in the table may not be strictly relevant to this discussion, as the overall artificial ceiling lighting is on in the inner two-thirds of the office for most of the time, though fewer draughtsmen worked at the innermost row of boards.

It is interesting to compare the occupants' assessment of the "brightness" of their daylighting with their assessment of glare and with the level of daylight illumination on the working plane. Offices with a high rating of comfort always contain a proportion of people who believe they could do with more light in spite of the fact that most of them have a reasonable quantity of daylight (e.g. Nos. 1, 4, 2, 3, 10).

On the other hand those with a low rating of comfort (e.g. No. 6 and possibly 9 (which was a pilot experiment and rated slightly differently in the questionnaire)) have a proportion of people who rate them as too bright even at low levels of illumination.

Independently of these remarks by respondents, it was noted that in the offices with artificial lighting (particularly in offices Nos. 2 and 3), when daylight illumination lessened appreciably, draughtsmen in those regions of the office furthest from the windows tended to switch on artificial lighting—despite the fact that the amount of daylight falling on the working plane was more than ample for the work (over 30 lm/ft^2). On the other hand almost all draughtsmen declare that they prefer to work by daylight rather than any other illumination whenever possible, and many in the worst lit offices refrained from switching on the local board lamps, even when daylight declined to extremely low level.

Appendix 2

Satisfaction with lighting compared with other features

It should be noted that satisfaction with lighting cannot wholly be separated from satisfaction with other office features, and for two

Table 14

Ten offices ranked by satisfaction with lighting, together with satisfaction for space and layout

Rank Order	Office No.	Satisfaction Lighting %	Satisfaction Space %	Satisfaction Layout %
1	1	82	75	78
2	2	79	88	86
3	3	76.5	75.5	78
4	9	68	68.5	68
5	8	67.5	77	74
6	7	66.5	72.5	68
7	6	56	34	44
8	4	55	65	64
9	10	51.5	52.5	52.5
10	5	43	35	45.5

reasons. One is that lighting is a consequence of the design of the building, so that good lighting in modern offices and poor lighting in out of date ones is the general rule. Where a new building is purpose-designed, architects and employers will probably make more effort to see that lighting corresponds with layout and equipment, whereas in an old, ill-adapted building, poor lighting often goes with cramped layout and out-worn equipment. The second reason is that draughtsmen tend to perceive their surroundings as a whole and rate any individual feature, not abstractly, but in relation to the general prevailing office conditions, a point that became clear in many interviews. Consequently, the satisfaction expressed with different office amenities tended to vary only slightly for each office. It is important to bear this point in mind when discussing differences between incandescent and fluorescent lighting, since these systems are, in general, characteristic of old and new offices.

In order to scale respondents' answers for each office, each respondent's replies were separately scored for each amenity and weighted for his attitude to his job and prospects, his past experience, etc. This gave a satisfaction index for each office covering lighting, space, and layout. This figure, expressed as a percentage, represents the average degree of satisfaction with each of these amenities, and enables all the offices to be compared. Table 14 shows the satisfaction index for lighting and the other office features.

Appendix 3

Day and night pictures of the offices studied in the survey

Fig. 1. *Office No.* 1—*daylight.*

Fig. 2. *Office No.* 1—*artificial light.*

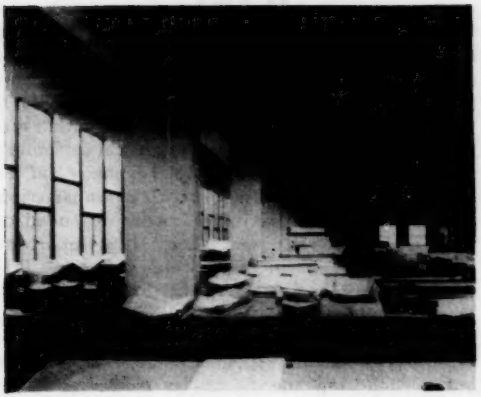

Fig. 3. *Office No.* 2—*daylight.*

Fig. 4. *Office No.* 2—*artificial light.*

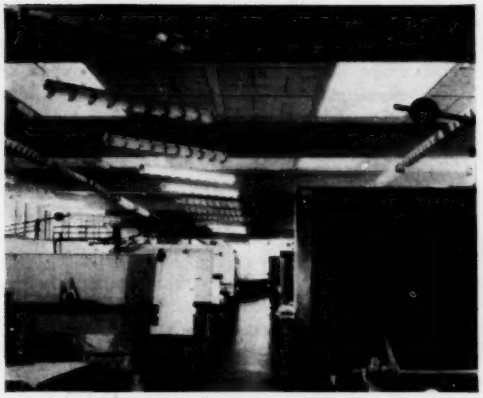

Fig. 5. *Office No.* 3—*daylight.*

Fig. 6. *Office No.* 3—*artificial light.*

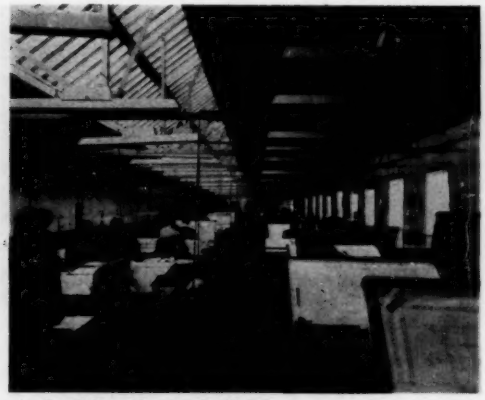

Fig. 7. *Office No.* 4—*daylight.*

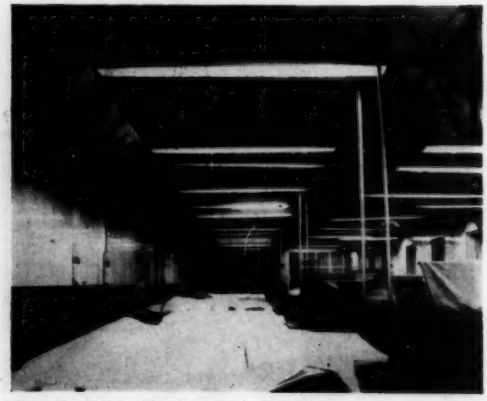

Fig. 8. *Office No.* 4—*artificial light.*

Fig. 9. *Office No.* 5—*daylight*

Fig. 10. *Office No.* 5—*artificial light.*

Fig. 11. *Office No.* 6—*daylight.*

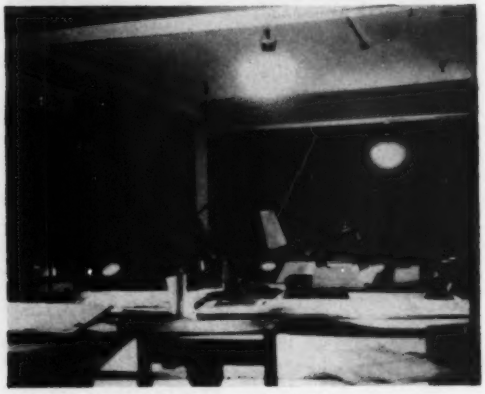

Fig. 12. *Office No.* 6—*artificial light.*

Fig. 13. *Office No.* 7—*daylight.*

Fig. 14. *Office No.* 7—*artificial light.*

Fig. 15. *Office No.* 8—*daylight.*

Fig. 16. *Office No.* 8—*artificial light.*

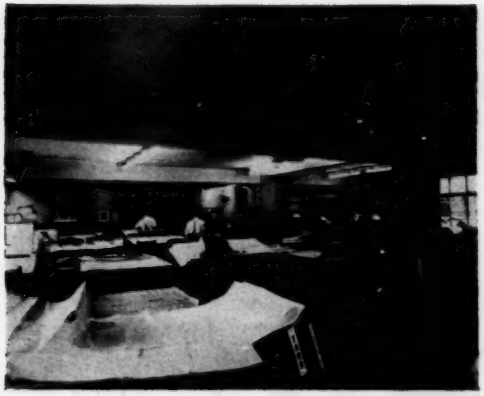

Fig. 17. *Office No.* 9—*daylight.*

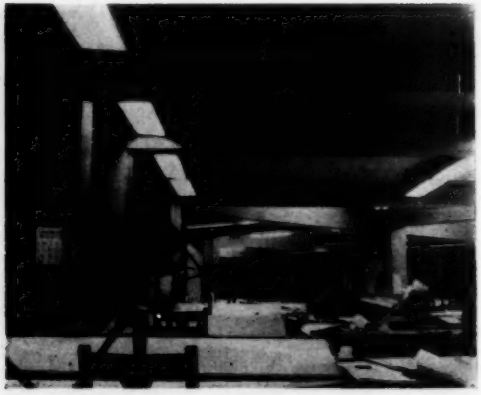

Fig. 18. *Office No.* 9—*artificial light.*

Fig. 19. *Office No.* 10—*daylight.*

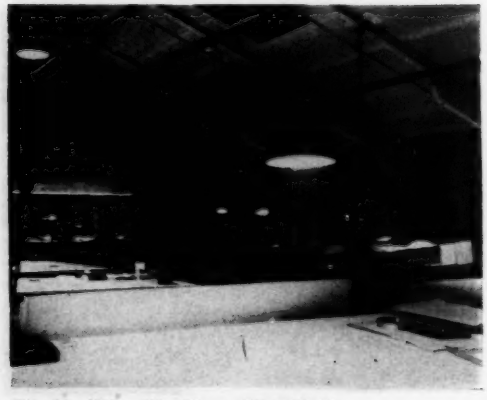

Fig. 20. *Office No.* 10—*artificial light.*

Discussion

MR ARTHUR HALL: The paper we have just heard is one that has been needed for a long time but obviously it could only result from the long and careful research that has gone into its preparation. The change from local tungsten to general fluorescent lighting in drawing offices is by no means complete yet, but has progressed far enough to enable a valid assessment to be made and as can be seen from these results one's satisfaction is largely dependent upon what one has been used to.

As a draughtsman of about 40 years experience I have covered the field of drawing board illumination from an oil lamp on a farmhouse kitchen table, through a Tudor office in Lincoln's Inn lit by gas brackets and a wide range of glass, metal and plastic shaded filament lamps suspended by runners and wheels from overhead cables and of mobile extensible lamps fixed to wall, table or drawing board (liable at crucial moments to subside limply like a melting wax giraffe) to very efficient overhead tubular fittings employing colour matching fluorescent tubes. Each type has some merits but there is no question in my mind that the fluorescent tube in a properly designed reflector properly mounted is the best all-round illuminant for the drawing board.

There is a curious anomaly in the work of architects which may occur in other professions; that is that as one's eyes get older and therefore more reluctant to accommodate, one's work gets into ever smaller scales. The juniors take over the $\frac{1}{4}$ in. scales and prepare $\frac{1}{2}$, $\frac{1}{8}$, 1 in. and full size details, whereas the experienced older architect spends his time making $\frac{1}{8}$ in. scale schemes some of the time, but when his work is on large projects the scale goes down to $\frac{1}{16}$ or $\frac{1}{32}$ in. to a foot and even to 1/500th scale. In my experience, the smaller the scale at which one must draw the higher and more shadow free must be the illumination. Even then there is an increasing risk of glare as the intensity increases and even when glare is not obviously present, high intensity light reflected from paper or tracing media can be very enervating. I think there is much scope for research into the best colours to be used, not only in drawing media but in the environment of high intensity illumination.

Some years ago, when using general and local tungsten lighting in our drawing offices we received a number of complaints of poor lighting. There was nothing consistent about them, so one night when the office was empty I took a photometer to every drawing board, typewriter and desk in the place and recorded the results. I found a variation of between 5 and 45 lm/ft.^{2} and that the complaints did not come from the lowest or highest illuminated positions, but in the middle. A subsequent change to general fluorescent lighting overcame the complaints. That study conforms well to the pattern that the authors have revealed; which suggests that much more than engineering is involved. It is obviously a matter of psychology. There is resistance at first to the unfamiliar which later becomes accepted as an improvement by the most conservative. There is an obvious relationship between the age of the draughtsman and the intensity of illumination and there is a very close relationship between the illumination and the size or scale of the task and the degree of accuracy required. I would like to know more of the relationship between visual acuity and intensity of illumination, the effect on accommodation of varying intensities of illumination, and the inter-relation between illumination, colour and acuity.

There are suggestions in the paper that visual flicker may be a cause of discomfort. This is often associated with power factor variations and such variations are often unavoidable in factories where, for example, a great deal of electric welding plant is used intermittently. That is an electrical problem requiring close attention.

I am generally opposed to mixing fluorescent and filament lighting in drawing offices, on account of the pools of different coloured light that occur on the drawing surface, which can be very confusing; and where colour matching is required such a mixture is impossible.

In regard to daylighting I am in agreement with the conclusions in this paper that an even indirect skylight as from northlights or shaded monitors is best. There are practical difficulties with either kind however. One of the worst is the need to prevent condensation of moist air in contact with the glass in cold weather, as even distilled water dropping from above ruins drawings. One can provide condensation channels but they will not prevent drips from falling from the astragals or glazing bars. Alternatively, one can use laylights under the glazing but these obstruct a great deal of the light and become dirty quickly. I am now completing a very large drawing office (500 × 53 ft.) illuminated by south windows and by north windows alternately direct to the sky and indirectly borrowing light from the east—west monitors of the factory, together with twin northlights. The northlights are being glazed with plyglass comprising $\frac{1}{4}$ in. wired plate inside, a glass silk sandwich and a clear glass external layer. This gives excellent diffusion and should overcome much of the condensation trouble. Admittedly, it reduces the illumination as compared with a single sheet

of clear glass but preliminary readings that I took recently on a grey day suggest that the intensity through the plyglass will be about one half that from the sky direct.

The other serious problem with roof-lit drawing offices is one that needs the urgent and careful attention of illuminating engineers. That is the combination of day and artificial sources in such a way that the latter do not impede excessively the former. A solution has yet to be found of the difficulty experienced by architects who design their roof sections with some precision to achieve high daylight factors, only to find that access of daylight is obstructed in a very serious degree by all the sheet metal work, tubing, cast iron boxes and other gear put up in the roof spaces by the illuminating engineers. It might be said that early co-operation with the engineers would obviate this, but in our experience it is not so. There seems to be something incompatible in the desire to obtain both day and artificial lighting from the same positions and directions. We must be grateful to Mr Collins and Dr Langdon and their research team for all the excellent work they have done in this study and for the valuable information contained in their paper and in the advice they give, resulting from their conclusions.

I suggest that new drawing office buildings should be designed to give a daylight factor of 10 per cent before the illuminating engineer gets to work with his paraphernalia, as that may achieve the recommended 5 per cent when he has done his work.

I also suggest that contrast ratio of daylighting and artificial lighting should not exceed 1·2 generally and never go beyond 1·3; and that the daylight factor curve should be as straight and level as possible.

In regard to artificial lighting I would suggest that there should be general lighting of the greatest possible extent in area of the least possible source surface brightness, arranged at such a level that the required 50 lm/ft² can be achieved without glare and so far as possible without any bright source being visible. These may be difficult standards to achieve but having achieved so much already I am sure that the rest are capable of achievement.

Finally, and though it may be a pipe dream I do not think it is so far off as may be imagined, I suggest that the plyglass glazing of northlights such as I described earlier should be energized to emit artificial lighting which would exactly reproduce the daylight which normally passes through it. It could be controlled by photo-electric cells so that as the daylight failed it would switch itself on automatically and the change-over would be virtually undetectable. Perhaps the lighting industry would like to take that as a goal and a challenge.

MR E. C. BENSTEAD: As a Chief Draughtsman of the Post Office Engineering Dept. I have the personal day-by-day supervision of a large drawing office comprising 130 staff, occupying the eighth floor of a new building in the City of London. The burden of my comments will be devoted to lighting difficulties in that office, or series of offices, into which we moved from older accommodation more than a year ago, the older accommodation being the offices designed Nos. 5 and 6 in the authors' survey.

I find it difficult to criticize the paper for two reasons: Firstly I am not competent to question the authors' methods of assessment, although I am pleased to note that they have given due prominence to user reaction and preferences instead of just 'blinding us with science'; and secondly I find myself in almost complete agreement with their conclusions which offer a firm basis for the design of artificial lighting installations in older drawing offices, and postulate the best daylighting conditions for any new offices.

My reasons for concern for the well-being of drawing office personnel are essentially practical, based on an increasing demand for top-class drawings, diagrams, technical illustrations, graphical statistics, etc., all of which are required at greater urgencies in a shorter working week. All personnel are thus required to work at top efficiency at all times. The pressure beats acutely on the tracers who prepare the final tracings, often after only a few months training, and a recent physiological survey in our drawing offices has demonstrated that tasks involving close visual inspection occupy 60 per cent of a tracer's working time; the corresponding figure for the draughtsman is 30 per cent.

For years we languished in the comparative darkness of offices Nos. 5 and 6 in the survey report. In these we had a level of general lighting of 3·5 lm/ft² but with the benefit of a 40 watt spotlight on each drawing position we managed tolerably well. Since coming into the relative limelight of the new offices with a general lighting level of 25/35 lm/ft² at the drawing board but with no local light, we are in trouble. In fact, there is a wide range of troubles that cannot be blamed entirely on to the lack of local lamps, or, perhaps, the draughtsmen's embarrassment at being, for the first time, so much in the light.

There are at least six of these offices, housing

30/40 staff in each. The offices are 20 ft. wide and the daylight enters by windows at the left-hand side in every case. The staff have perforce to be double-banked, so that those remote from the windows have poor daylight, while after dark, those at the windows have a preponderance of artificial light on their right-hand side and little reflection from the blackness of the window spaces on their left. All staff complain of excessive brightness overhead, particularly when they look up, which is accentuated by the long runs of light source against the relative darkness of the ceiling and the top half of the one wall that provides any reflection at all (incidentally the wrong wall for craftsmen whose equipment is designed for left-hand light).

As a result of staff complaints, a survey has just been made of their reactions to the present lighting arrangement, after 15 months experience of it. Here are some of the reactions.

65 per cent of the staff cannot see clearly at their drawing board with artificial lighting.

52 per cent consider this general lighting to be too bright.

70 per cent make specific complaint of shadows.

94 per cent ask for the provision of a local light that they can control.

The figures for the female element of the staff, i.e. 50 tracers and drawing office assistants, were higher, and it was significant that one third of all staff have visited the optician or occulist in the last 12 months, 55 per cent of all staff wear glasses for some detail of their work, and 50 per cent of all the women (who are comparatively young) have had glasses prescribed at some time or other in the last two years. I wouldn't attempt to draw any widespread conclusions from these returns, other than to confirm that our consultant physiologist is convinced that there is considerable evidence of strain, and to say that we will be doing something about it forthwith. I am convinced, however, that lighting systems that employ fluorescent tubes need very careful arrangement; that drawing office personnel and all others who do close work, need a local light that they can control themselves; and that there is an element in fluorescent lighting which seems to irritate some people at all times.

Except for the last point, which might be controversial, the other difficulties seem to have been foreseen by the authors, and I would like to congratulate them on their conclusions.

MR W. K. LUMSDEN: I notice also there were one or two omissions from the authors' paper which rather surprised me. Firstly, there is the question of specular reflection from the paper on the drawing boards. This is a complaint which I find is very common in drawing offices and I am rather surprised it was not mentioned specifically because it does affect the design of lighting installations fundamentally. Another point which rather surprised me was the fact that there was no mention made of glare from local lighting fittings, although the general illumination was of a very low order in a number of instances. There is one case where the general illumination was about 3 lm/ft^2 and I would have thought that, with local lamps, a certain amount of glare would have been caused. A further point affecting the satisfaction of the draughtsman is the colour of the tubes. In practice, this has a considerable effect upon their reactions to any lighting installation, and I would like to know if any particular complaints were made on that aspect. Finally, Tables 7 and 8 give the user's reaction to fluorescent lighting. I would have liked to have seen similar tables giving the user's reaction to tungsten lighting.

MR JOHN RATCLIFF: I am responsible, with my Partner, Mr Howard Lobb, for the design of office No. 2 which figured in the authors' paper. It is of interest that our clients were not attracting sufficient draughtsmen and for this reason required better drawing office conditions. As a result of the new drawing office, it was estimated that the drawings production went up by some 20 per cent which was the equivalent of that number of additional draughtsmen, and it undoubtedly shows that the good deal of money spent on this installation paid handsomely.

When we were discussing our proposals, almost 100 per cent of the draughtsmen were opposed to doing away with the local lamp, but I think it can be said that they are now reconciled to not having a local lamp. I would say that the key to the situation is undoubtedly in the design of the actual lighting system and particularly its directional effect.

Now I would like to introduce something else which has not been mentioned at all, but which I think is very important in assessing the comfort aspect which formed part of the installation—the question of sound absorption. As has been indicated in the paper, a large part of the time is not spent drawing at all, but consulting with one another, on the telephone, etc. In the system of lighting which we saw in office number two, the overhead parabolic curves had behind them sound absorption and heating, and I am quite sure that a large degree of satisfaction comes about through this sound absorption, which shows that it is very important to assess these comfort factors as well as illumination.

The authors have mentioned the use of artificial light with daylight. As I understand it from Dr Hopkinson's recent contribution on this subject, I think much more study could be given to this possible combination on restricted sites. On such sites, where land values are often high, it is not always going to be economic to achieve a top lit office only 20 ft. deep, and at office number two, where the lighting is controlled by photo-electric cells, it could be said that the combination of the daylight and artificial light is reasonably successful. You may say, of course, that it costs money to have artificial light on all the time, but on a restricted site, comparing the floor space that you might lose with the cost of installing and running the installation, it may well be the right approach to consider a combination of daylighting and artificial lighting.

MR STANLEY LYONS: I regret very much that no mention is made in the paper of the angle of the drawing board. This has a very profound influence on the value of directional quality of the light, especially for people who work on very large boards, such as antiquarian boards and those used in ship drawing offices. When the board is up, you cannot see in front of you at all; your entire view is of the board itself, and a very directional system is excellent.

I believe in using only fluorescent tubes for drawing offices, and I have some years' experience on the board; but I must say that when one is doing certain types of artistic work it is very useful to have some incandescent light coming at a close angle so that you can see the shine on a pencil line or ink line. On a survey that I did recently, the clients were very keen to have fluorescent lighting in the general drawing-office, but the tracers had to have local lamps which, they pointed out, can be used for drying the ink!

The orientation of the draughtsman to his immediate surroundings is of great importance. If you study the relationship of the drawing board to the natural lighting and the reference table you will see that a draughtsman at work turns every way. Where he has his reference table at right-angles to the board it is quite impossible to get satisfactory arrangements with local lighting only. I would refer you to a paper presented by J. M. Attwood and John M. Tebby (*Trans., Junior Institution of Engineers*, April 1952) on this subject.

People will put up with extraordinarily bad lighting for a long time until someone starts to grumble. There is a psychological factor in this; if it is a happy office they will put up with dreadful conditions, but if it is not, the 'grumble-point' is soon reached for all.

On the question of some people not liking fluorescent light scientifically or economically, there are some other less usual grounds; there is a publication referring to the fact that certain people suffering from epilepsy find that flicker will precipitate an epileptic fit.

MR J. B. HARRIS: The authors have successfully pinpointed the main problem in the drawing office, i.e. should we provide a scheme of good general lighting only, or should there be general plus local lighting. The work with which I am concerned is that of adapted rooms in existing buildings, some of which have been shown on the screen this evening. These rooms may well be used for many different purposes and are often of awkward shape. There may be ceiling beams of various depths and irregular positioning of piers and columns. None of these factors helps the general lighting solution and thus there is no 'cut and dried' plan for this type of interior. We have carried out several field tests of different types of general lighting schemes. We started off in a small office with a few draughtsmen and then experimented in larger offices having up to 50 persons. We found that the majority of draughtsmen still expressed a strong desire for a local adjustable lamp. Not only are there detailed tasks which are variable in their visual demands but furthermore, as pointed out by a previous speaker, the actual working plane can vary from the horizontal or near horizontal to a vertical or near vertical poistion. Also you never have the same visual requirements at all drawing board positions at the same time. Obviously the simplest method of providing a flexible system of lighting to suit everybody is one in which there is complete individual control of a local lamp. An additional advantage of this local lamp is that it will produce a shadow where required—for example it will help to determine the position of a previously made compass point indentation. Many draughtsmen work on tracing paper which has a relatively high and visually disturbing specular reflection factor. Rather than provide an overall illumination of 72 lm/ft^2 based upon the Australian recommendations, it is surely more economical to install a local lamp and provide a general illumination of 20 to 30 lm/ft^2. Facts such as this must always be considered by managements, for few will agree to finance an expensive scheme if acceptable results can be achieved in a cheaper manner. I do suggest that, if the local lighting fittings are of sound construction and do not require excessive maintenance,

it should not be impossible to overcome the difficulties that sometimes arise when positioning socket outlets to suit various board positions.

The authors' investigation covers a number of different lighting systems and I think it is rather unfortunate that in their excellent survey user reactions to illuminated ceiling installations were not obtained.

MR H. E. BELLCHAMBERS: One of the telling points of the authors' paper put forward in favour of the local light, was that it gave the kind of distribution which was the best for visual acuity and comfort, in that the brightest part of the scene is the drawing board and it allowed simple and careful gradation of the light outwards from that position. In natural lighting, that condition is largely absent and I do not think that this fact was considered in the paper; I would like to know whether any questions were asked about the use of local artificial lighting together with daylighting in any of the installations that were studied.

MR A. G. SMITH: Much of the discussion this evening has centred on the question of adjustable local lights and I would like to call attention to one of the statements made in the summary of the paper, i.e. 'The absence of local adjustable lamps resulted in more complaints of glare and over-brightness.' I do not think that such a conclusion is entirely justified, as the coincidence of the absence of the local lights and the conditions stated, is not proved as a case of cause and effect. Surely the complaints of glare and over-brightness result from conditions created by the unsuitable nature of the general lighting introduced. In the last of the colour slides that we were shown, where the B.R.S. louvred fittings were portrayed, it was demonstrated that comfort was improved by reducing the contrast between the luminance of the boards and the fittings. In the demonstration this contrast was reduced by increasing the illumination on the boards themselves by means of local lighting. I think this is putting things the wrong way round and the better way would be to reduce the luminance of the general lighting fittings as seen from all normal viewing angles. I would suggest that the design of the B.R.S. fittings may require some such modification when used for providing such high levels of illumination.

Table 9 is concerned with the differing attitude to fluorescent lighting of users and non-users. I endeavoured to draw some conclusion from this and found the evidence seems to suggest that, with increasing years, one makes up one's mind about things affecting one's self, but becomes disinterested in other peoples' worries. Since the table is concerned with attitudes, perhaps the technical setting was of less importance.

MR J. M. WALDRAM: Mr Ratcliff referred to the brightness of the ceiling troughs in drawing office No. 2. This was very carefully gone into in the design; it could be varied by altering the finish of the troughs. It may be that the brightness chosen was lower than some would wish, or that the finish which was finally obtained differed from that which was specified; I do not think that it is too low. This lighting system is specially interesting as being one of the few which provide a high illumination with directional control of the light and independent control of the ceiling luminance.

MR R. L. C. TATE: It was quite clear from a number of slides including the last that over-brightness of the lighting fittings can be a serious difficulty, and this seems to suggest that whenever possible we should go in for a built-in system of overhead lighting and control the ceiling brightness very carefully.

If we must use lighting fittings, then their position and orientation is of the utmost importance: in many of the cases shown not enough care was taken in choosing the fittings from the point of view of their appearance when seen from a distance, nor in their orientation, and this, rather than the illumination, must have very much influenced the reactions of the draughtsmen to them.

MR R. R. HOLMES (written contribution): Mr Collins and Dr Langdon are to be congratulated on their confirmation by statistics of what had otherwise been largely a matter of experienced personal opinion. Their investigation, however, was restricted to a limited number of installations, and it is regretted these did not include certain other types held to give considerable satisfaction.

It would be interesting to have the authors' views on the relation of lighting equipment position, type and orientation to drawing board and plan-table location and inclination, for the three or four furniture arrangements commonly used in drawing offices. Little reference to this aspect appeared in the paper, but it may have been included in the work on the survey and would be of value to the planning engineer.

One other point is particularly intriguing—would the authors be kind enough to give their explanation as to why office No. 1 is regarded as highly satisfactory when its average illumination figure is so far below that recommended for ordinary office tasks?

DR LANGDON (in reply): First I would like to deal with the point raised by Mr Harris, who pointed out that we did not include an example of a luminous ceiling in our study. This is perfectly true, but it must be remembered that there are many kinds of natural and artificial lighting which were not included in the survey. I think you will agree that we should have had to increase greatly the number of sub-groups for study and this would have added materially to the difficulties of the survey. When comparing different systems, the total sample would have had to be re-divided and subdivided a number of times to take care of the various examples—luminous ceilings, various kinds of troughed or louvred fittings, the directional trough ceiling (as in the case of office No. 2) and so on. The number of study sites would have had to have been increased by two or three times to avoid the reduction of sub-groups to insignificant proportions. Though it would undoubtedly be interesting to make a study of luminous ceilings it would have been impractical in a study of the kind we were making. If you do include a single example and consider it simply as a case of general lighting, I do not think the information derived from that example would result in the sort of comparisons Mr Harris would like to see made.

The second point raised related to Table 8 and respondents' attitudes to fluorescent lighting. That table, and the one following, dealing with the attitudes of different age groups, suggests to me that although people do get more set in their attitudes as they grow older, when they actually experience something which is real and tangible, and seems to them an improvement, they are just as prepared to change their attitudes toward it as are younger people.

If we look at the attitudes shown in these tables, for users and non-users at different ages, we find that among older non-users, a greater number are opposed to fluorescent lighting, whereas the younger non-users are more favourably disposed to it. When they all come to use it however, we find the older men just as strongly in its favour as are the younger men. Older people may have certain attitudes in the absence of experience, but they appear to modify them in the light of it as easily as younger men.

Finally, someone asked why we did not ask a similar set of questions about tungsten filament lighting. The reason is quite simple. Filament lighting is not new or controversial. For this reason people do not expect to be asked whether they have an 'attitude' about it. They take it for granted. You cannot sensibly ask people if they are in favour of bread or matches. On the other hand, fluorescent lighting is new and controversial and people do not express surprise at being asked what their attitude to it is, since they feel that they can be expected to have an 'attitude' about it like most new things. If you asked them similar questions about ordinary electric lighting they would begin to wonder what you were looking for. In any case, even if you obtained answers to such questions they would be of little value for you could not compare them with answers to similar questions about fluorescent lighting.

MR COLLINS (in reply): With regard to Mr Lumsden's point on specular reflection, I have not got the figures in detail but it was found that in about 10 per cent of the cases specular reflection was a serious problem, in something like 40 per cent of cases it was a slight problem and I quite agree that specular reflection difficulties cannot be ignored. I think the most interesting point is the question of the brightness of fittings. If you want to use a general lighting system without local lamps on your board it is extremely difficult to get the right brightness distribution and the right amount of light on to the board from the right angles. Now you can make your fittings of lower brightness but if so you only get vertically downward light. To get light from over a wide angle, your fittings must have a certain brightness and that brightness is almost certain to be very much brighter than the board and so you are back at this difficulty again. The B.R.S. fitting was designed to have not too high a brightness and to a specification which a lot of people thought was absurdly low in brightness. Even so, when you get a lot of them and you are trying to light your drawing boards by no other method they do in fact become glaring and I think that is what has given rise to some of your remarks.

Mr Waldram pointed out the fact that with the trough ceiling in office No. 2 you can adjust the brightness. This is a very valuable thing to be able to do as I think we showed you by the use of the slides in the double projection. Perhaps we do not quite agree with the final brightness which was arranged or perhaps in fact the brightness which was decided upon originally was not the one which finally occurred in practice but this is an example of how you can work and design to produce the required environment. You have the illumination you want on the boards from very wide angles of incidence and you can adjust the brightness of the ceiling to suit.

THE AUTHORS (communicated reply): In answer to Mr Hall, we would say that there is a large

amount of data in the literature on the relationship between illumination, or brightness and contrast of task, and visual acuity and other measurable characteristics of vision. Where the data is lacking is in being able to determine objectively the effect of such things as comfortable arrangement of the brightness ratios in the field of view, stimulation provided by careful design of colour treatment and choice of source colour, etc. At the moment, the only way we can do this is to try to compare the effects of these things on the attitudes of the subjects towards their surroundings and their work.

We have not found much opposition to the mixing of filament and fluorescent sources, provided that one or the other of the sources is well screened and cannot be seen as a visible source of light. Condensation on rooflights we would have thought was a thermal problem to be solved by some form of double glazing or by movement of warm air past the surfaces as part of the ventilation system.

If we understand from Mr Hall's remarks about daylight that he is asking for artificial light to reproduce daylight exactly we are not sure that we fully agree. This point was raised again by Mr Bellchambers. Because, on the whole, draughtsmen prefer to work by daylight rather than by artificial light, we do not think this necessarily means that the former has the best possible characteristics of distribution for their work. It would be very interesting if we could produce artficially exactly the physical properties of daylight and compare satisfaction with that system with satisfaction with a system which we thought might have a preferable distribution of illumination and brightness.

We did not ask any questions specifically about the use of local lights during the daytime, but it is perhaps of interest to note from Table 12 that even in summer about half the draughtsmen use artificial lighting at some time or another.

Although we did not discuss specular reflection in the paper, the subjects were asked if they were troubled with reflections from tracing cloth or objects around the work point. Only for about 10 per cent of all subjects did these reflections cause serious trouble, and only 32 per cent of the subjects admitted to having even very little, or indeed any, trouble at all. We do, however, feel that this is an important point to be borne in mind when designing an installation, and it becomes even more critical when considering the lighting for tracers' tasks.

We have not had any complaints of glare from local lights as such, but it has not been possible to be precise about these questions, as it is not easy to convey to the subject the exact sensations you want him to describe. There is no doubt in our minds that even when some of the installations were rated as comfortable, the levels of general lighting were far too low for any reasonable degree of comfort, let alone visual performance.

We have not had any particular complaints about the colour of fluorescent tubes, although some may well be concealed in the 'other bad points' section in Table 8. We do not think it would be possible to draw any conclusions as to the preferred colour of tubes from the small sample used.

We were very interested in Mr Ratcliff's comments on the benefits of improving the drawing office conditions. We do believe that the benefits of an improved environment, perhaps just not of lighting alone, but when integrated with heating, acoustic treatment, layout and equipment, can be seen in concrete form, if not always translatable directly into money. We also hope that when more experience is available of the use of permanent supplementary artificial lighting, the economic balance between this form of lighting and the construction of the building to rely entirely on daylight for most of the day, will become more clearly defined.

The drawing boards in the offices which are visited were tilted at all angles, from nearly horizontal to nearly vertical. If the fully tilted type of engineering board is used, plenty of light must reach it from sources not directly overhead, and this is one of the reasons why the opaque trough type of fluorescent lighting fitting is not satisfactory for this kind of application, except in the special form used all over the ceiling in office No. 2, which was probably (with the B.R.S. fittings) one of the two general lighting schemes which were successful in illuminating the tilted boards.

The necessity mentioned by Mr Lyons for the draughtsman to use a reference table in addition to his drawing board, and the large proportion of time which we have shown is spent in calculation and consultation, are the reasons why we would insist that the general lighting of the office should be of a high standard even when local lights are used on the boards It is, however easier to get a good level of illumination on a flat surface where less exacting tasks are performed and there is less likelihood of being troubled with shadows from drawing equipment etc.

It is a fact that fits can be induced in epileptic patients by intermittent photic stimulation at the correct frequencies, but we do not know of any evidence that properly installed and maintained fluorescent lighting can do this. We do believe however that a very small number of people might

suffer slight disease when working in fluorescent light, and we would recommend that such a case should be treated sympathetically. A tungsten local lamp should relieve any trouble of this sort.

We agree with Mr Smith that the glare complained of in some instances in the general lighting installations is most likely due to the unsatisfactory nature of the general lighting installation, but the general picture obtained from the survey indicates how difficult it is to get good general lighting without glare, and how much less critical is the general installation if local lights are provided to distract the attention from it.

In reply to Mr Holmes' written question on layout, a study was made of the layout and equipment requirements independently of lighting. We do not think it usually wise to relate the lighting specifically to one layout, because this generally changes more frequently than the lighting installation.

The explanation for the high rating of office No. 1 in artificial lighting would seem to be that the draughtsmen rate the convenience and high level of illumination from the local lamps, and the relative comfort of the glass-steel diffuser fittings so highly that these factors outweigh the difficulty of working with not more than 11-12 lm/ft^2 on their reference tables.

UDC 628.978

Application of Regulations Relating to the Lighting of Ships

By J. T. GRUNDY (*Member*)

Summary

The paper reviews briefly the numerous classes and types of Royal Navy and Merchant ships, and, in relation to lighting, the multitudinous national and international regulations, together with statutory instruments. Navigational and Command Bridge electric lamps and lighting equipment are discussed. Interior lighting practice for all ships is reviewed and recommendations are made. A special section is devoted to the use of the various forms of discharge lamps in ships.

(1) Introduction

In presenting this paper the author feels it necessary to introduce the world of shipping to the lighting engineer. Surprisingly enough no such introduction seems ever to have been made on any substantial scale, even though lighting in some form or other must have been required in ships as soon as they attained any magnitude. In the *Acts of the Apostles*, Chapter 27, it is stated that the ship carrying Paul to Rome had aboard 'two hundred threescore and sixteen souls', which gives some idea of the size and development of ships even in those days.

The shipping world seems throughout its past to have been mainly preoccupied with matters such as navigational hazards, mechanical construction, economy and development of propulsion and safety at sea, to such an extent that marine lighting has been woefully neglected. Such preoccupations on the part of the marine authorities must inevitably increase the problems facing the lighting engineer, who finds himself in a completely unfamiliar world surrounded by a mass of rules and regulations. An explanation in broad outline of the world of shipping should, however, help him towards a better understanding of these problems.

(2) The Ship

(2.1) General classification

Ships are very varied in size and construction, to serve the various purposes for which they are built. There is, however, one generally familiar method of classifying them all, and that is by tonnage. The world's gross tonnage of merchant shipping in July 1958, was 118,033,731 tons, of which the British Commonwealth accounted for a total of 20·88 per cent[1]. The world's gross tonnage of fighting ships is believed to be in the region of 93,000,000 tons[2].

(2.2) Merchant ships

Merchant ships range from passenger liners of the size of the RMS *Queen Mary* and the RMS *Queen Elizabeth* down to small coasters, and they include tankers, dry-cargo ships, pilot vessels, tugs and the like.

(2.3) Fighting ships

Fighting ships range from obsolescent battleships through aircraft carriers, cruisers, destroyers and frigates to minesweepers and submarines; and with the advent of nuclear propulsion the last-mentioned is in the process of becoming a true submarine.

(2.4) Interpretation

It is most important for the lighting engineer to appreciate that a ship of any size is in fact a floating 'town'. In shore language it includes power station, broadcasting and receiving stations, homes, factories, warehouses, cinema, accommodation for recreational activities such as indoor and outdoor games, restaurant, hospital and school. Add to these the complication that the whole 'town' moves, may have to contend with arctic and tropical climates and carries all the machinery and other facilities required for moving; and the lighting engineer will quickly realise that the whole I.E.S. Code for Lighting in Buildings is applicable to the lighting of a ship, though the added factors of naval architecture and construction and international requirements will necessitate some modification of ideas.

(2.5) Personnel

(2.5.1) *The Royal Navy*

The duties of all personnel in the Royal Navy are clearly defined in Queen's Regulations and

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Admiralty Instructions. It is worthy of note that one of H.M. Ships may be commanded by officers of various ranks, such as Lieutenant or Lieutenant Commander. Of particular interest to the lighting engineer is the Electrical Branch, which was formed in 1947 from a nucleus of R.N. torpedo officers and R.N.V.R. electrical officers.

(2.5.2) *The Merchant Service*

The man of supreme authority in a merchant ship is the Master, though he is often called the Captain, which is for him merely a courtesy title and, strictly speaking, a naval rank. Under the Master comes the Chief Officer, the Second Officer and so on. On the engineering side there are the Chief Engineer and his assistants, together with the Chief Electrical Officer or Chief Electrician and his assistants, all of whom carry heavy responsibilities.

The lighting engineer should note that the majority of merchant ships do not carry an Electrical Officer, and, without implying any disrespect to the high qualifications and qualities of marine engineers, this point should be borne in mind when planning ships' lighting equipment.

(3) Ships' Regulations and Classification Societies

(3.1) Statutory instruments

Generally speaking, merchant ships are built to meet the requirements of statutory international authorities and of national governments. British ships are required to comply with Ministry of Transport Regulations. (See Appendix 1.)

(3.2) Classification societies

Though not a legal requirement, nearly every sea-going ship is registered with a classification society. To be eligible for registration a ship must comply with the rules of the particular society concerned. For British shipping the most important of such societies is Lloyd's Register of Shipping, which absorbed the British Corporation Register in 1949. It is a voluntary association of shipowners, shipbuilders and underwriters instituted primarily for the purpose of surveying and classifying ships of any nationality and disseminating this information through the medium of the annual publication of Lloyd's Register Book.

(3.3) Marine insurance

The shipowners' mutual insurance associations, and particularly the protection and indemnity clubs, have played a large part in British shipping, marine underwriting having been carried on for centuries. Lloyd's—an entirely separate organization from Lloyd's Register—is, of course, world-famous. The protection and indemnity clubs, which are known by the short title of 'P. & I. Clubs', are formed by shipowners to secure cover for risks, which are outside marine insurance policies and which may be better understood as third-party risks.

(4) Ships' Electrical Rules, Supplies and Regulations

(4.1) Rules and regulations

It is the responsibility of the Ministry of Transport to maintain standards in ships flying the British flag. In addition, there are the rules of the various classification societies, which, though largely based on the I.E.E. regulations, differ slightly from one society to another. (See Appendix 1.) Some of the tanker companies' requirements are more severe than those of the classification societies, which do, however, include special sections in their rules to cover the particular requirements of tankers.

From the point of view of the illuminating engineer it is worth noting that all the regulations deal primarily with electrical, mechanical and safe construction, as distinct from illuminating engineering.

(4.2) American regulations

The authority responsible for the American regulations is the American Bureau of Shipping, whose practice is similar to that of its British counterpart. Insurance is arranged by the American marine insurance underwriters.

(4.3) Electricity supplies

In general, a ship may use either an a.c. or a d.c. system and both systems have numerous supporters. The systems of distribution most commonly used are, for direct current, the two-wire insulated system, and, for alternating current, the three-wire, three-phase system with insulated neutral. A certain amount of work has been done in this country and in the U.S.A. on the earthed neutral system, as distinct from the unearthed system. Various classification societies, however, stipulate in their rules for tankers that the insulated system shall be used. Thus, where instant-start fluorescent tubes are concerned, the lighting engineer will immediately realise that he is at once in difficulty.

(5) Superstructure

(5.1) Lighting for navigation

The International Conference on Safety of Life at Sea was held in London in 1948[4], and among many other activities it revised the International Regulations for Preventing Collisions at Sea. Since then the British Government has issued Cmd. 9050, which ratifies the agreement reached at that conference. Ratification has also been forthcoming from forty other countries, but not yet from the Argentine, China and Ceylon among others.

The collision regulations, which are very complex, attach very great importance to lighting, requiring red port and green starboard lights shining over certain areas, mast lights, stern lights and the like. In combination these lights present a vital pattern and tell an immediate story to the mariner at night, simply by their bearing, configuration, colours and number. These regulations are at present being severely criticized from many aspects, one being the lack of adequate definition of many of the terms used[5]. They do, however, specify the arcs of visibility and the distances at which the various lights shall be visible in clear weather, as well as their exact positions on the ship. (See Appendix1.)

Current regulations state that as a general rule 40-watt lamps, giving a candle-power of approximately 32 candles, will be satisfactory. Some owners are, however, known to favour 100-watt lamps, though use of the more efficient gasfilled lamps would obviously involve an immediate change in colour transmission. These regulations were initially based on oil lamps and were subsequently amended for the use of 40-watt and 60-watt squirrel-cage vacuum lamps to B.S. 555:1939. The Board of Trade originally specified that the lamps to be used should be 32-candle-power carbon-filament lamps with two 16-candle-power filaments in parallel, the idea being that, if one filament failed, the other would continue to give a reduced light until the lamp could be replaced. When metal-filament lamps came into general use, however, the B.O.T. abandoned its insistence on double-filament lamps and specified lamps with cage-filaments consuming not less than 40 watts. The reason for insisting on this type of filament is that with the dioptric lenses used for navigation lights a certain vertical length of light source is essential.

The Survey of Light and Sound Signals lays down the colours of the navigation lights in terms of limit glasses. These glasses, whether used with an oil lamp at 2,000°K or with a vacuum tungsten-filament lamp at 2,360°K, give a signal within the required colour range. The National Physical Laboratory is believed to be deeply interested in the colour-transmission properties of all signal glasses, which constitutes a wide field for useful research.

The regulations of the I.E.E. and Lloyd's Register and the I.E.C. recommendations (Publication 92) are clear and emphatic on the prime importance that navigational lights shall be on separate circuits and be capable of being changed over from the bridge in the event of supply failure. Moreover, visual/aural indicators have to be provided to give an immediate alarm when a lamp fails. Fig. 1 shows a typical navigation lantern and Fig. 2 the associated warning indicator.

In May 1960 there is to be a further International Convention for the Safety of Life at Sea, and in preparation for it many professional bodies are endeavouring to produce agreed reports for submission to their governments.

(This Conference took place from the 17th May to the 17th June, 1960, and proposed an extension of some regulations dealing with machinery and electrical installations in both cargo and passenger ships, and made specific provision for the use of radar in reduced visibility or fog.

A general distinguishing signal for all fishing vessels, consisting of a coloured light (e.g. red for hampered drift-net vessels and green for a trawler) over a white light at the masthead has been laid down. Other modifications have been made in provisions dealing with the use of navigation lights between sunrise and sunset, and the disposition of navigation lights. There are numerous other modifications. The 'date of coming into force' will be 12 months after a certain number of countries have ratified the Convention, and will no doubt be promulgated in due course.)

(5.2) Command bridge lighting

In the matter of command bridge lighting current practice may again be considered to be completely out of date. On a ship's bridge instruments of vital importance, such as compass, telegraphs, rudder indicator, engine-revolution indicator, lookout indicator, telephones, logs and the like, are spaced out over the area, as shown in Fig. 3. Lighting engineers will immediately notice the unshaded 60-watt lamps, which are not, of course, used at sea at night. Under conditions of night adaptation, which takes some thirty minutes for the human eye, the instruments are illuminated by small individual lamps. For example, Regulation M424 of Lloyd's Register simply states that the current input of a lamp for illuminating the compass card is not to exceed 0·6 ampere; this is, of course, on account of magnetic effects. The usual

Fig. 1 (*left*). *Navigation light lanterns; top masthead or towing; below, stern.*
Fig. 2 (*above*). *Navigation light indicator.*

practice is to insert red filters in the instruments, though yellow ones might be preferable. The same problems arise here as in connection with the lighting of aircraft control panels, as has already been pointed out by J. W. Strange and B. Stevens[6].

In drawing attention to the wide field that is open for investigation on this subject, mention may be made of some work that one company is already doing in grouping most of the instruments together in a console, as in Fig. 4. This console, which is entirely experimental, embodies two bridge telegraphs, one being of fairly normal design, while the other is operated by push-button.

(5.3) Chart rooms and tables

The bridge chart table and its adjustable lighting unit can be seen in the background of Fig. 3. When laying a course or entering the position on the chart it is vital that the mariner does not destroy his night vision. Hence, it is again customary to use a red filter. This fact is, however, very surprising for a variety of reasons. One is that on each chart is a compass rose, sometimes placed with its north-south axis near the meridian, and at night it is extremely easy to make a mistake on such a chart. Moreover, certain new charts are being coloured to accentuate shoal water, dangers and land contours. In fact, more than half the people at sea do not normally use the compass rose, particularly at night or when illumination is poor. The general procedure is to use the parallel rulers. Most surprisingly, the original Decca charts had their hyperbolae coloured green, red and purple, which look very similar under dim red light; now the red is being changed to chocolate. Much experimental work has been done with amber light, but as yet only a grey mass is seen with this light. Urgent attention should be given to this question of chart and chart-table lighting; in his moments of greatest stress the mariner is working under the worst possible lighting conditions.

(5.4) Deck and emergency lighting

Any exterior lighting on a ship may be a source of confusion to the mariner at sea; hence, it is little used. In harbour, certain bulkhead fittings already provided in cargo ships are used to facilitate movement, as also are cargo clusters and floodlights for off-loading the cargo. With the increasing popularity of alternating current more consideration should be given to discharge lamps, such as the 250/400-watt MBF/U lamps, as distinct from the present filament lamps fitted in floodlights with their abbreviated life owing to heavy vibration. In passenger ships enclosed boat-decks are illuminated, but here again care has to be taken to pre-

Fig. 3. *Bridge of a ship.*

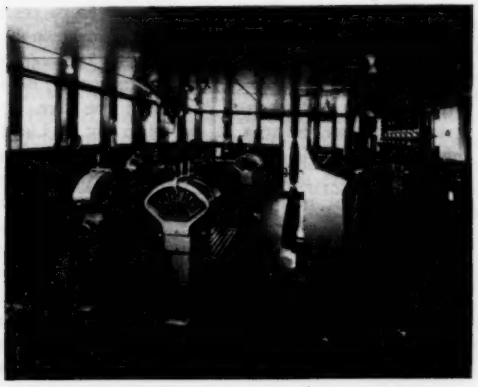
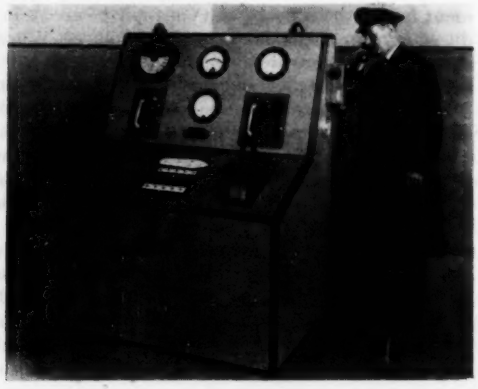


Fig. 4. *Bridge console.*



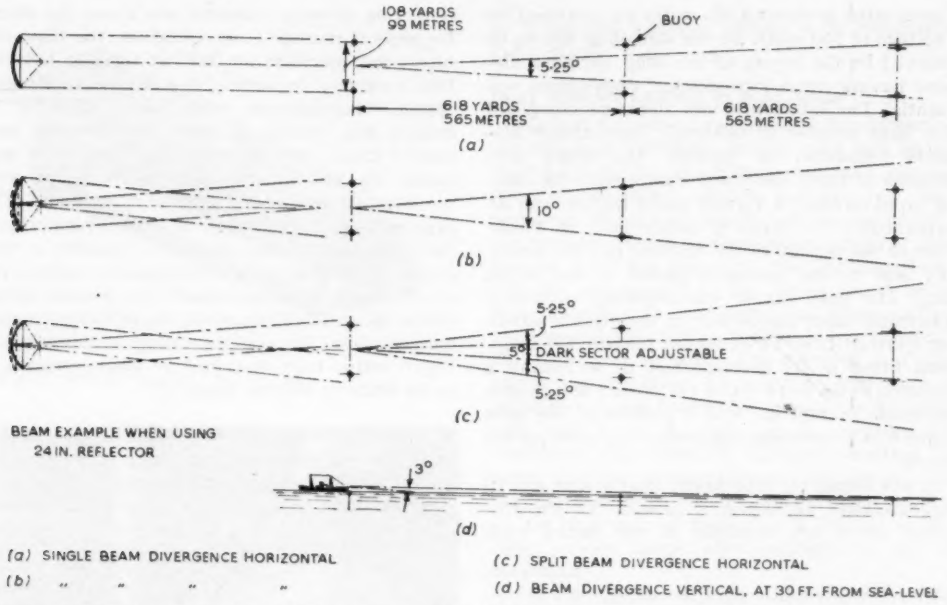


Fig. 5. Showing use of adjustable split beams from canal searchlights to illuminate buoys and banks of a canal with minimum interference to other ships.

vent interference with navigation. Normally, all boat-deck lighting is extinguished at night at sea, unless it does not interfere with the bridge at all.

The relevant authority in the case of emergency lighting is the Ministry of Transport. Such emergency supplies in passenger ships are required to energize bilge pumps, watertight doors, the ship's emergency lights at every boat station on seck and overside, in all alleyways, stairways and exits, and also navigation lights. Here, however, only emergency lighting on deck is under discussion. All the regulations are quite clear as to what is meant by watertight, waterproof and dripproof, but Lloyd's Register's M.1012 and I.E.E. 1002 (A) refer specifically to a 'glass receptacle'; it is assumed, however, that in their revisions due attention will be paid to plastics. It is not compulsory for emergency deck lighting fittings to be watertight; in fact they may be open. Nevertheless, in providing for them the lighting engineer will be well advised to recommend watertight fittings within the specification of the Regulations, and consideration should be given to armourplate glass.

(5.5) Canal searchlights

For navigating through the Suez Canal—and also the Panama Canal—stringent regulations were laid down by those canal authorities in the interests of safety and continuous free passage. The then Suez Canal Maritime Company laid down clearly their requirements relating to searchlights having a split beam (Fig. 5).

(5.6) Signal lamps

Day and night signalling lanterns are an M.O.T. requirement under Section 27 of the Merchant Shipping (Safety and Load Line Convention) Act 1932, and must be arranged for emergency-battery operation. The signal lamps have to be approved by the National Physical Laboratory before acceptance by the M.O.T. and it would seem that great strides have been made here as compared with navigation lights. The signal lamp must have an axial candle-power in the beam of not less than 60,000 candle-power and the light distribution must be carefully controlled. Some lanterns have 'six-filament' lamps and other rapid-nigrescence lamps, which will be discussed in the next paragraph.

(5.7) Rapid incandescence and nigrescence lamps

Lamps for signalling at sea must be highly resistant to shock and vibration. For this particular application, to give the desired beam candle-power,

a lamp rated at about 3,000 watts was required for a voltage of 200 volts. As the signalling was to be achieved by the keying of the lamp circuit, a filament having rapid incandescent nigrescence was essential. The light source was, therefore, composed of a large number of relatively low-wattage filaments connected in parallel, the small wire diameter of these low-power components facilitating rapid cooling. A further novel feature was incorporated in the lamp to ensure that the breakdown of one section of the filament did not inevitably lead to the complete failure of the whole lamp. The light source was required to have a sufficiently rapid nigrescence to maintain a signalling speed of 12 to 14 words per minute; the lamp, when fitted in its housing, had to withstand a vibration of up to 14 cycles per second at a double amplitude of 1/10 in.; and a portion of the light source had to continue operating even after partial failure.

It was found by experiment that a wire size of approximately 16 mgms. is suitable for the filaments, which are arranged in two banks, each consisting of seven filaments one above the other. To prevent damage from vibration, the filament-supporting members are held at top and bottom. This is effected by anchoring a number of straight vertical molybdenum wires to cross-pieces of steatite and winding a coil of molybdenum wire around these vertical wires in a number of segments, the spaces between them coinciding with the filament intervals in the vertical plane. The gaps in the coils then form the loops for supporting the filaments. By this means it is possible to produce a fairly close loop, which serves to reduce the amount of filament movement. To prevent arcing on the failure of one filament, the supports are split into two legs. The complete lamp is illustrated in Fig. 6 and is fully described in 'Improvements in multi-filament electric lamps'[7].

(6) Ships of the Royal Navy

(6.1) General requirements

The Admiralty, naturally, has its own specifications for all equipment, but the remarks already made regarding lighting for navigation, command-

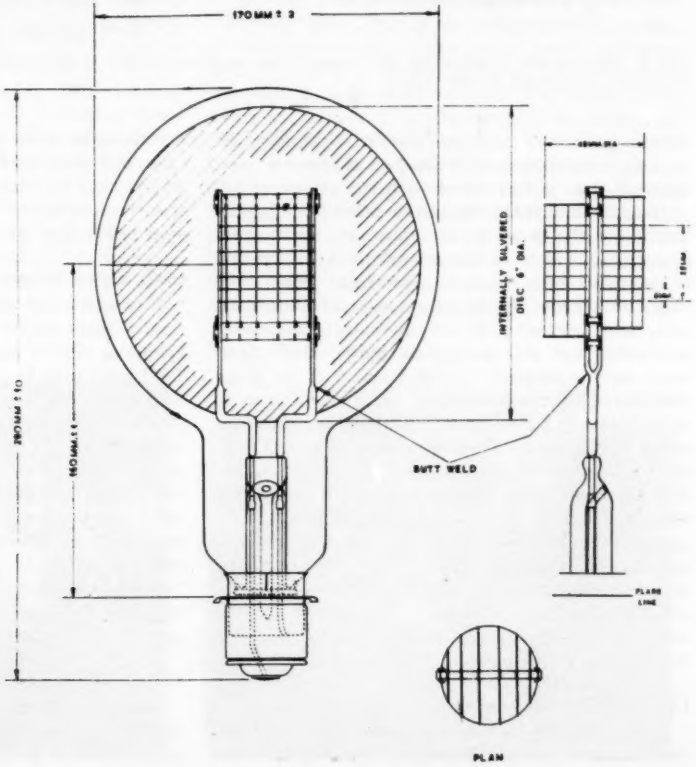


Fig. 6.
High nigrescence lamp.

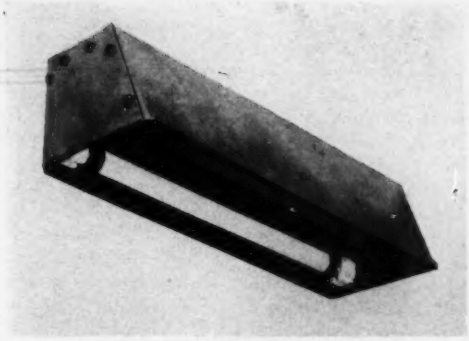


Fig. 7. 'Weston' low level lighting unit.

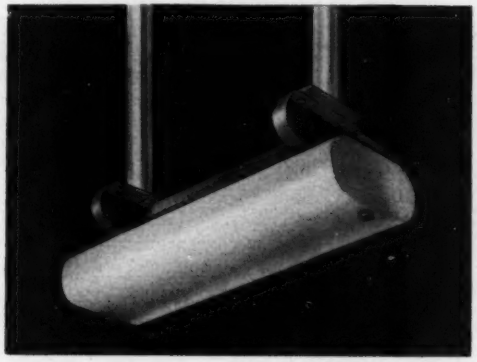


Fig. 8. Admiralty fluorescent fitting.

bridge lighting and signal lamps are equally applicable here. There is no doubt, however, that the Royal Navy has made greater progress than the Merchant Service in its facilities for chart-room lighting and other ancillary services such as radar rooms, anti-submarine cabinets, radio rooms and the like, using fluorescent fittings and dimming devices as well as ultra-violet light and coloured lighting.

Mr H. C. Weston has carried out considerable experimental work in some of these cases with low-level fittings mounted below eye level for ease and safety of movement in radar rooms and with fluorescent chalk and ultra-violet light for battle-position marking. One experimental fitting is shown in Fig. 7. Here, however, it is proposed to discuss only certain specialized lighting units, and it should be borne in mind that it is customary to standardize on a unit and give it an Admiralty pattern number purely for logistic reasons. Moreover, it is normal practice to provide the majority of Admiralty lighting fittings with compressive cable glands.

(6.2) Interior lighting in H.M. ships

The last ten years have seen the development of the standard Admiralty fitting using two 20-watt fluorescent tubes, which were originally operated from starter-switch circuits but are now relay-operated. This fitting, which is illustrated in Fig. 8, can be used with either alternating current or direct current. It is felt that both the light distribution and the appearance of the fitting could be improved by the use of coloured end-pieces and possibly reeded sides with a bottom louvre in place of the plain acrylic bowl. The coloured end-pieces might also be given some other significance. In addition to these fluorescent fittings the Admiralty uses such items as wall-map illuminators, self-contained relay-operated emergency-battery lanterns, sick-bay operating-theatre fittings and what are known as Type S rough-service filament lamps. In the war year of 1940 over 3,700,000 of these rough-service lamps were produced in one factory[8].

For the interiors of submarines the latest fitting uses two 6-watt 9 in. fluorescent tubes. Through the genius and perseverance of Rear-Admiral Hyan George Rickover, U.S.N., and his team, nuclear power-units have now become available, and it is obvious that the lighting engineer will have to pay a great deal more attention to the lighting of submarines. The familiar day-night cycle will be lost, and, though submarine crews are specially selected, the increased operating time under water may be expected to give rise to psychological problems.

(6.3) Superstructure lighting in H.M. ships

In some respects, as already noted, ships of the Royal Navy have similar requirements to those of the Merchant Service. In aircraft carriers, however, there are also the special requirements for deck surface landing lights[9], which are dimmer-controlled, and for the mirror landing light, which replaces the illuminated bats.

(7) Interior Lighting in Cargo Ships

(7.1) Crew accommodation

Various regulations, including artificial lighting ranging from 4 to 15 lm/ft^2, were laid down in S.I. 1953 No. 1036, and subsequently revised to give more realistic figures ranging from 2 to 8 lm/ft^2 (see Appendix I). It is worthy of note that the figures are not average ones but for specified positions. While particular attention is paid to natural lighting and to flooring and bulkhead con-

struction, lighting engineers will observe with concern the unavoidable regulation which specifies headroom of 6 ft. 3 in., 7 ft. and 7 ft. 6 in. Such low mounting heights obviously involve serious risk of glare. Bunk lights are adequately covered, but far more attention should be given to average illumination, to colour, to closely specified light distributions and to the brightness of lighting fittings.

(7.2) Cargo spaces

The illumination in cargo spaces, naturally, depends largely on the type of cargo the ship is built to carry. In some ships it is customary merely to pass a cargo cluster through the hatch, when required. The more modern ships are, however, being equipped with lighting in just the same manner as storerooms ashore. The main aims are to prevent pilfering and to promote safety of movement. The latest ships with a.c. supplies incorporate extremely heavy-duty fluorescent fittings using 20-watt 2 ft. tubes capable of withstanding rough usage. In any cargo-space lighting care has to be taken with colour rendering, because owing to the illiteracy of some foreign stevedores it is the practice to use colour marking for identification purposes.

(8) Passenger Ships (Accommodation)

Sufficient is known about interior lighting practice to enable any lighting engineer to deal effectively with passenger ships, provided that he bears in mind the various regulations previously mentioned, remembering also that all lighting on board must be capable of withstanding the rolling and pitching of the ship.

Fluorescent tubes of both the hot-cathode and cold-cathode types are finding increasing use in ships, and when these are built into cornices and the like, it is important to note the positions of the air-conditioning ducts, so as to avoid the possibility of cold air being blown on to the tubes at particular points. A later section is devoted to the subject of discharge lamps and tubes in ships. At this juncture it is sufficient to draw attention to the vital importance of colour rendering and the necessity for avoiding glare, particularly in dining spaces and the ship's shops. Complete illuminated ceilings are not to be recommended because of the difficulty in obtaining uniform brightness.

(9) Tankers

(9.1) Growth and electricity supply

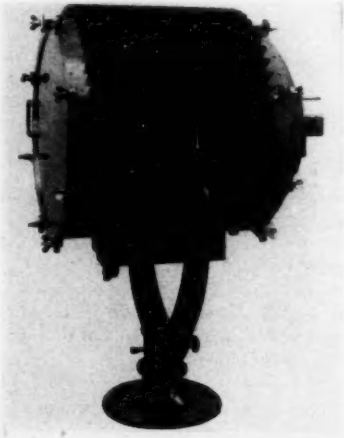
The extensive growth of the oil industry over the last twenty years has caused far-reaching changes in the world's tanker fleets, both in size and type of vessel[10]. For tankers carrying oil with a flashpoint of 150°F (65·5°C) or over there are no special requirements, but for flashpoints below this temperature there are special rules.[3].

As far as the lighting engineer is concerned, the electricity supply most likely to be available is an a.c. system. For lighting, cabin fans and socket outlets, Lloyd's Register's Regulation 1503 did specify a maximum of 115 volts a.c., though the 1947 I.E.E. Revision allows only 110 volts. These are under consideration for revision. I.E.C. Publication 92 seems to ignore this fact. Elsewhere in the ship a maximum of 250 volts a.c. may be expected for heating and cooking equipment, and the same relaxation may eventually be expected for lighting voltages, as Lloyd's Register has already allowed.

(9.2) Lighting fittings

Lloyd's Register specifies that, except in accommodation sapces, enclosing cases of lighting fittings shall be wholly of metal and watertight or flameproof, but weatherproof fittings are permitted in engine-rooms, store-rooms, dry-cargo holds and similar safe places. (See Appendix 1.) Similarly, navigation and signal lights may be weatherproof. In cargo pump rooms and similar spaces flameproof fittings (Group 2) should be used and reference should be made to I.E.S. Technical Report No. 1. In between deck spaces immediately above any oil tank and on decks within a distance of 10 ft. from any oil or vapour outlet the fittings should also be certified flameproof. Reference is made in various publications and regulations to the term 'gastight' or 'gasproof', but as there is no general agreement as to its meaning, it is advisable to use certified flameproof equipment whenever

Fig. 9. A tanker searchlight.



doubt arises. Fig. 9 shows a so-called 'gasproof' tanker searchlight approved by the Suez Canal Authority.

(9.3) Lighting practice

In tanker engine-rooms it is customary to use drip-proof 80-watt 5 ft. fluorescent fittings of a special design to facilitate maintenance. In tankers it is of vital importance that all electrical installations shall be efficiently maintained, and in particular deck lighting fittings should be frequently examined. The greatest possible care must be taken of all flameproof fittings.

(10) Discharge Lighting in Ships

When manufacturing discharge-lamp fittings for ships the necessary control gear should be made suitable for both arctic and tropical conditions, and the vibration to which they will be subjected should also be borne in mind. Certain lampholders used ashore are quite unsuitable for use in ships, and while there are no regulations as to the wiring in such fittings, it is essential that it be of the highest possible quality. Finally, it must not be forgotten that the colour coding of cables to British practice differs from that of certain foreign countries, and is is, therefore, essential to provide adequate marking and wiring diagrams.

(10.1) Hot-cathode lighting

There is today a wide variety of fluorescent tubes in various sizes and wattages from 6-watt 9 in. to 125-watt 8 ft. tubes in numerous colours, and with various circuits such as switch-start, instant-start, rapid-start, pulse-start and the like. Ashore, the majority of such tubes are used on a.c. systems, their use on d.c. systems being restricted owing to the cataphoresis problem and the low efficiency obtained. Afloat, more and more hot-cathode fluorescent tubes are being fitted aboard ship despite the drawbacks of d.c. systems, and as the number of ships having a.c. systems increases, there will probably be the same expansion in the use of such tubes as has been seen ashore in industry and commerce.

(10.1.1) *Hot-cathode tubes on d.c. systems*

The circuit most commonly adopted for hot-cathode tubes on d.c. systems is that including a resistive ballast, a choke coil and a thermal starting switch with the normal MCF/U tube, the longer tubes being used on 200-220 volt systems and the shorter ones being operated either singly at 100-120 volts or two in series at 200-220 volts. With a starting circuit having a thermal relay starting switch and conventional tubes the circuit must include an inductive choke to provide a voltage surge for striking the tube, when the relay contacts open. The main advantages of this circuit are that the tube and the starter are standard items, starting conditions are reasonable, and the average lamp life of 5,000 hours is the same as with a.c. circuits provided that the polarity of the supply is reversed at regular intervals. The main disadvantages are the watts loss in the resistive ballast and the long reclosure time of the thermal switch.

As previously indicated, Admiralty fittings on d.c. systems use two 20-watt 2 ft. tubes with a special circuit, which works very well. The disadvantages are the rather high initial cost and the fact that the relay is special.

A major advance took place in the form of a 2 ft. d.c. fluorescent tube capable of operating from standard ships' mains without reversing switches or ballasts[11]. In this case a special type of fluorescent tube MCFD/U is operated in series with a barretter type ballast known as a stabilizer. The 20-watt 2 ft. tubes embody their own starting aid, consisting of internal electrodes in strip form. The particulars are shown in the Table below.

The tube life is given as 2,500 hours as compared with the normal 5,000 hours. The advantages of

Tube Type	For use on Mains Voltage	Average Through Life Lumens per tube †WW	Average Through Life Lumens per tube DLWW	Watts Loss in Auxiliaries	Overall Watts	Overall Average Lumens per Watt †WW	Overall Average Lumens per Watt DLWW
15 in. 14w MCF/U	110 or 72	448	322	(110v)28	42	10·7	8
18 in. 15w MCF/U	110 or 72	555	405	(110v)24	39	14	10
24 in. 20w MCFD/U	110	780	580	(110v)19	39	20	15
24 in. 20w MCFD/U*	220	690	510	(220v)34	74	18·6	14

* To be operated two in series.
† WW—warm white; DLWW—De luxe warm white.

these circuits are that starting is automatic and virtually instantaneous and the tubes have low brightness and high resistance to vibration. Provided that the tubes are protected from draughts, polarity reversal is not essential; if they are subjected to draughts, end blackening may result. On a 220-volt d.c. system a 120-volt 40-watt filament lamp may be used as a light-producing ballast.

(10.1.2) *Hot-cathode tubes on a.c. systems*

With a.c. systems the usual high efficiency of 30-50 lumens per watt is attained without the disadvantages of d.c. operation. Moreover, as the polarity reverses every half-cycle, the loading on the tube electrode is balanced. During one half-cycle one electrode acts as cathode and the other as anode; during the next half-cycle the roles are reversed. With d.c. systems one electrode acts as cathode and the other as anode until the polarity is reversed. Unless the reversal of polarity is automatic, it is unlikely that the burning times on opposite polarities will be balanced, with the result that one electrode will be operating as cathode longer than the other. In all probability, therefore, this one electrode will fail owing to loss of emissive material while the other is still in relatively good condition.

In a.c. systems aboard ship, as already mentioned, the voltage to earth is limited by I.E.E. Regulation to 150 volts although this may be regarded as under consideration. The supply for lighting is, therefore, usually obtained from a delta-connected transformer with a phase voltage of 230 to 240, 50/60 cycles.

Fluorescent tubes with glow or thermal switches for striking the arc will operate without difficulty on such a supply. In the case of instant-start circuits, which are obviously preferable, the supply situation—whether 'line-and-earthed neutral'. centrally earthed or non-earthed—has an important influence on the voltage required to start a fluorescent tube. On a 'line-and-neutral' system the earthed stripe on the instant-start tube or the adjacent earthed fitting is in effect connected to one tube cathode when a conventional transformer-type instant-start circuit is used. On switching on, therefore, nearly full mains voltage appears between the fitting or the stripe and the other cathode. There is, therefore, a steep voltage gradient between this cathode and the earthed stripe, since they are separated by only a short distance. This gradient assists the ionization of the gaseous filling and in conjunction with the voltage applied between the ends of the tube causes it to strike.

On centrally earthed and two-and three-phase star-connected systems, where tubes are operated between phases, the voltage between tube cathode and earthed stripe or fitting will be considerably less than the supply voltage, i.e. $< \frac{V}{2}$ or $< \frac{V}{\sqrt{3}}$ (since some 10 volts are also lost in the choke). Owing to the reduced voltage between stripe and tube a higher voltage is needed across the tube to cause it to strike than would be necessary on a conventional 230 volt 'line-and-neutral' system. An additional 50 to 60 volts are needed to strike an 80-watt MCFA/U tube on a centrally earthed (150 v.) system at 20°C.

Considered from the point of view of tube starting 'floating', i.e. Delta systems are regarded as being centrally earthed, since they can simulate this condition, as they are often 'tied down' by capacitances to earth. In any case the centrally earthed condition is the worst that can arise; for, if the potential between one tube cathode and earth decreases, that between the other cathode and earth will increase and tend to assist starting. The worst striking condition prevails when both tube cathodes have the same voltage to earth. There are two ways of overcoming this difficulty; one is to design suitable gear to provide the additional voltage needed to start the tube under these adverse conditions; the other is to apply along the tube an insulated metal strip, which for safety reasons is connected to one side of the supply through a high resistance. The voltage between the metal strip and one tube cathode is then approximately equal to the supply voltage; the tube behaves as though on an earthed neutral system, and striking is much improved. The provision of such a strip has the advantage that standard control gear can be used, but it is not easy to apply in manufacture when a variety of different designs of lighting fittings are involved. The alternative arrangement has the disadvantage that gear has to be specially designed and manufactured; it has, nevertheless, been applied in fittings containing 6, 8, 15, 20, 30, 40 and 80-watt tubes[12].

Dimming circuits for fluorescent tubes on a.c. systems can be provided by electronic and other means. When deciding to install hot-cathode lighting in a ship, however, even if it has a d.c. system, it is preferable and more generally efficient to provide an alternator for the lighting; and many alternators of suitable design are available. Future design work in connection with hot-cathode tubes will obviously include transistor circuits for low direct voltages of 12-24 volts; some such circuits are in fact already available. An increase in the use of the 9 in. and 12 in. tubes is also to be expected in bulkhead fittings.

(10.2) Cold-cathode lighting

Both hot- and cold-cathode tubes produce visible light mainly from a coating of fluorescent powder on the inner wall of the tube[13]. The forerunner of the cold-cathode tube was the neon sign[14]—a generic term embracing all high-voltage illuminated signs and displays—andvirtually the same circuits and tubing are used in both cases. There are obvious advantages in that the tubing can be tailored to fit into any particular designer's scheme for the ship's interior, and a wide range of colours is available. The efficiencies range from 13 to 40 'lumens per watt, with a life of 20,000 hours, and compared with filament lighting in particular the need for special media to provide coloured light is eliminated.

Cold-cathode tubes are less efficient than hot-cathode on a.c. systems. They require bulkier control gear giving high voltages, and metal-sheathed ozone-proof cable has to be provided for such high-voltage circuits. B.S. 559 requires the cable ends to be terminated in porcelain insulators sealed with compound against the penetration of moisture and ozone[13].

Cold-cathode lighting is forbidden in tankers and in the case of other ships special notice has to be given to Lloyd's Register. A notice 'Danger, switch to be locked in the "off" position before touching' has to be displayed and maintained at all points of access to the cold-cathode tubing and where otherwise necessary. Generally speaking, the cold-cathode fluorescent tube has lost popularity ashore, except for special tailor-made applications. Its running cost is estimated to exceed that of hot-cathode tubes by 30 per cent[15].

(10.3) Other discharge lamps

Up to the present the well-known range of 80/125/250/400-watt MB/U and MBF/U lamps has found few applications on board ship; this is probably due to the inherent delay of 10-20 minutes in their warming-up time. The same remarks apply to sodium lamps. For deck work in harbour, however, such lamps will probably come more to the fore in the future.

(11) The Future

Throughout the world there is a tendency for small nations to start operating their own fleets of ocean-going ships. Recently the ports of the world have seen the flags of Bulgaria, Rumania and Communist China, together with those of Nationalist China, Venezuela, Ceylon, Ghana, Nigeria and the United Arab Republic.

The United States Maritime Administration has allocated more than £100,000 for research and development of new navigational aids and safety devices. On the British side the Hydrodynamics Laboratory of the National Physical Laboratory was opened recently, having cost £2,000,000. The British Shipbuilding Research Association has instigated a project for investigating vibration and noise in ships in a special £20,000 laboratory.

No one appears to have carried out much research on the subject of low deckheads, and the application of the B.R.S. glare formula is to be strongly recommended. Some consideration should also be given to specifications for ship-lighting fittings from the point of view of illuminating engineering, as distinct from that of pure mechanical/electrical engineering. The United Kingdom did not regard the United States of America as a maritime nation, but high praise is due for the recently issued American I.E.S. 'Recommended Practice for Marine Lighting', which by their own admission has taken years of work by a committee of government agencies, naval architects, shipbuilders and lamp and lighting equipment manufacturers. They have been conservative with regard to illumination levels, but they have not sufficiently borne in mind the fact that it is possible to step out of a brilliantly lit interior into the complete darkness of a deck space at sea.

In so far as the electricity supply is concerned, the reluctance to change from the familiar d.c. system is attributable mainly to the ease with which that system can be adapted to marine requirements. By limiting the application of variable-speed motors, however, to services where they are essential, and by taking advantage of the advances made in industrial a.c. equipment it is practicable to use a.c. systems generally in ships. The maintenance costs are much reduced by adopting an a.c. system, mainly owing to the absence of commutators and the more robust construction of a.c. machines. Components for the installation of a.c. equipment have less weight and bulk and for a given power the conductors in a 440-volt three-phase a.c. system are of smaller size than those in a standard 220-volt d.c. system. Moreover, transformation of voltages to supply special services is a simple matter in an a.c. installation. Another point in its favour is that the general use of a.c. equipment ashore involves the electricity industry in a continuous programme of development, and the results of this work, particularly in the lighting field, have direct application in ships equipped with a.c. installations.

(12) Acknowledgments

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Appendix 1

Selection of rules and regulations of use to the lighting engineer concerned with ships lighting equipment.

1. Institution of Electrical Engineers "Regulations for the Electrical Equipment of Ships', Third Edition, September 1939, with the Supplement of November 1947. (Note: 4th Edition may be issued late 1960.)
2. Lloyd's Register of Shipping, Extracts from the Rules for the Construction and Classification of Steel Ships, No. 6, 'Electric Propelling Machinery—Electrical Equipment'.
3. International Electrotechnical Commission Publication 92, First Edition, 1957, 'Recommendations for Electrical Installations in Ships'.
4. U.S. Coast Guard Electrical Engineering Regulations, 46 CFR, Parts 110 to 113, inclusive (Publication CG-259).
5. The American Institute of Electrical Engineers Standard No. 45.
6. Statutory Instruments 1952 No. 1948, Merchant Shipping, Safety, 'The Merchant Shipping (Construction) Rules, 1952.'
7. Statutory Instruments 1953 No. 1036, Merchant Shipping, Masters and Seamen, 'The Merchant Shipping (Crew Accommodation) Regulations, 1953.'
8. Statutory Instruments 1954 No. 1660, Merchant Shipping, Masters and Seamen, 'The Merchant Shipping (Crew Accommodation) (Amendment) Regulations, 1954' and 'Crew Accommmodation in Merchant Ships', Code No. 55-348.
9. Union of South Africa Extraordinary Government Gazette No. 6318, 20th November 1959.
10. The Factories Acts 1937.
11. Dock Regulations 1934.
12. British Standard Code of Practice CP.1003: 1948. 'The Installation and Maintenance of Flameproof and Intrinsically Safe Electrical Equipment.'
13. The 'International Conference on Safety of Life at Sea, 1948', Cmd. 7492.
14. 'International Regulations for Preventing Collisions at Sea, 1948', Cmd. 9050.
15. 'Survey of Lights and Sound Signals—Instructions to Surveyors' 1927. Reprinted in 1955.
16. American Illuminating Engineering Society 'Recommended Practice for Marine Lighting.'
17. B.S. 555:1939. 'Tungsten Filament Miscellaneous Electric Lamps.'
18. B.S. 1376: 1953. 'Colours of Light Signals.'
19. Publication C.I.E. No. 2 (W–1.33) 1958.
20. Merchant Shipping (Safety and Load Line Conventions) Act, 1932.
21. I.E.S. Technical Report No. 1, 'Lighting in Corrosive, Flammable and Explosive Situations.'

Appendix 2

Extract from prior 1958/9 'Construction of Electric Propelling Machinery and Electrical Equipment' (Lloyd's Register of Shipping).

Standard systems

109. The following systems of distribution may be used:

(*a*) Parallel systems with constant pressure, either:
single wire with hull return; or with two-wire with direct or single-phase alternating current; or three-wire with direct current; or

three-phase three-wire; or three-phase four-wire.

(*b*) Series systems with constant current (direct current only).

Limiting pressures

110. The pressure of supply is not to exceed the following values:

(*a*) With direct-current constant-pressure systems—
for power, 500 volts.
for lighting and heating 250 volts.

(*b*) With alternating-current systems:
for power, single-phase, 250 volts.
for power, three-phase, 440 volts.
for heating and cooking if permanently connected to fixed wiring, 250 volts.
for lighting and socket outlets, 150 volts to earth.

(*c*) With constant-current series systems (direct current only), 650 volts.

For ships carrying oil having a flash point less than 150°F (65·5°C).

Nature of supply

1502. For direct-current systems the voltage of supply is not to exceed:
For power, heating and cooking, 230 volts.
For lighting, cabin fans and socket outlets in accommodation spaces, 115 volts.

1503. For alternating-current systems the voltage of supply is not to exceed:
For power, 250 volts single-phase or 440 volts three-phase.
For heating and cooking circuits if permanently connected to fixed wiring, 250 volts.
For lighting, cabin fans and socket outlets in accommodation spaces, 115 volts.

Appendix 3

Extract from 'Construction of Electric Propelling Machinery and Electrical Equipment' (Lloyd's Register of Shipping) 1959.

Standard systems

109. The following systems of distribution may be used:

(*a*) Parallel systems with constant pressure—
Direct Current
Single wire with hull return;
Two-wire;
Three-wire with mid wire earthed.
Alternating Current
Single-phase two-wire;
Three-phase—
Three-wire;
Four-wire with neutral earthed but without hull return.

(*b*) Series systems with constant current (direct current only).

Limiting pressures

110. (*a*) For parallel systems with constant pressure system voltages for both alternating current and direct current shall not exceed:
500 volts for generation; power; cooking and heating equipment permanently connected to fixed wiring.
250 volts for lighting, heaters in cabins and public rooms and other applications not mentioned above.

(*b*) With constant current series systems (direct current only) 650 volts.

111. In very large alternating current installations, generation and limited distribution at higher voltages (e.g. 3·3 kV) may be submitted for special consideration.

Special requirements for Petroleum Tankers and for ships carrying oil in bulk having a flash point less than 150°F. (65·5°C).

Nature of supply

1502. Lighting circuits, socket outlets and cabin heating circuits are not to have any electrical connection with a circuit (or source of supply) of higher voltage than those specified in M.110.

Discussion

MR J. G. HOLMES: Like a great ship, this paper covers a wide area with much below the surface that calls for exploration and knowledge before it can be fully understood. Lighting standards in shipping have arisen more from long tradition rather than from science or technology, and, as a result, they work with great reliability but little inspiration. In the public rooms, the lighting seems to have been developed by long-distance coaches out of Edwardian hotels and one feels that the techncial parts of ship lighting are based more on Rules or Statutory Instruments than on any text books or publications of this Society.

I recall that two or three of us had a meeting in the Admiralty a number of years ago, and we commented to one of their technical men on the use of carbon-filament vacuum lamps dimly lighting the corridors; his reply was 'Oh, you mean those half-watt lamps. Yes, we did try them when they first came out, but they didn't last long'. I have a feeing that this is the sort of tradition that runs right through to the lighting of ships; safety, security but not always efficiency. We have seen this evening some of the more advanced pieces of lighting equipment where efficiency is prominent, but somehow we expect to see them installed only in the very advanced ships with nuclear propul-

sion and radar navigation, rather than in the general run of merchantmen. This is an international problem and Mr Grundy has questioned whether this Society or this country has made an adequate contribution. We have led the world in many aspects of ship design, notably in the new N.P.L. testing tank at Feltham, but I wonder how much we have done in lighting the ships; perhaps this can be answered later in this discussion.

I wonder too how much regard we pay to the risk of fire when we design lighting fittings for ships. Steel ships are far from incombustible and the inductive electrical equipment, the high potentials and the high temperature of lighting fittings must represent a serious fire hazard. This does not seem to be covered in any detail in the rules and regulations, and I should welcome guidance on this point.

The comments in the paper on chart board lighting would horrify the average passenger if he thought they were true of his ship. It is very difficult, if not impossible, to distinguish between black, purple or blue lines of normal ink on a chart if one is to preserve a reasonable level of dark adaptation. It has been shown that for many observers a deep red light does not destroy dark adaptation and that a low illumination in red-orange light is also acceptable and much better in this respect than white or bluish-white light. Unfortunately, some charts require a high illumination and a blue-rich light for reliable identification of the printed lines and symbols, and such a light is bound to reduce the sensitivity of the navigator's eyes at night. I remember that the best compromise was investigated by R. W. Ditchburn in 1941 (Admiralty Research Report ARL/N5/0360), calling for absorption of all wavelengths shorter than 5,400 Angströms or thereabouts and giving an orange-coloured light in which red, brown, green and black lines could be distinguished and in which purple lines in a particular ink could be recognized as a slightly unusual pink. It is general experience that the red vision used in the dark adapted eye gives greatly reduced colour discrimination and it follows that special precautions are necessary to maintain the best compromise between the opposing requirements.

The lenses for masthead and side navigation lights are required to be designed to a strict arithmetical specification for the glass, laid down by the N.P.L. about forty years ago, and the polar curve of light distribution from such lights is also strictly defined, being not less than double the bare lamp intensity over $\pm 5°$ and not less than half at $\pm 10°$ from the axis. This specification was based on oil flames as the light sources and I wonder whether the accurately specified electric lamp which Mr Vaughan demonstrated has had a beneficial effect on the result. Perhaps the intensity distribution requirements are different now from those at the beginning of the century.

Finally, the red and green glass colour filters in the 1924 Board of Trade regulations were doubtless chosen after years of evolution by trial and error; like so many things which evolved naturally, they are a good compromise. Glassmaking has improved since that time and better filters are now available, but the Board of Trade 1924 colours comply with the current British Standard 1376 and with the C.I.E. international recommendations issued last year. They were the basis for railway signal colours, and the Class B limits in B.S. 1376 are closely consistent with present marine singalling practice.

MR P. CHITTENDEN: Ship lighting is not one of the easiest sides of our profession. It calls for a great deal of specialist knowledge and I think that it will be very useful to have this review of the rules and regulations which apply.

Those of us who are engaged in the lighting of ships find these regulations sometimes impose severe limitations, and this is not helped by the shipowners and the shipbuilders who in seeking our help do not generally call us in at the planning stages in the same way as the architects are now beginning to do. This is unfortunate as shipowners usually have their own particular requirements and ideas, within the framework of the regulations, which they also require to be met.

Lighting in the public rooms of ships was, until recently, regarded very much as part of the decorations and the amount of light in public rooms was very often negligible. The general trend of rising levels of illumination applies to ships, and with these increases in illumination levels the fluorescent lamp is now being used in considerable quantities. I think that this is a point that the authors could have elaborated and discussed in some detail. The power saved by using fluorescent lamps can, in a large ship, be considerable. If it is air conditioned then the saving is doubled.

Full emphasis of the requirement for crew accommodation lighting under Statutory Instrument No. 1660 (1954) has not been made in this paper.

Apart from a brief mention in the Factories Act of minimum lighting levels no other Government regulations exist which lay down minimum levels of illumination, and I feel that our Society should pay special attention to these regulations for this reason. Generally very little is known or published in regard to the lighting of small rooms. We can refer to our I.E.S. handbook for the larger

spaces, but when designing lighting installations to given levels of illumination in a series of cabins say 10 ft. × 8 ft. there are no tables to which we can refer and the only methods are to build an experimental cabin or that of trial and error.

In a small room of this size the amount of reflected light which contributes to the overall illumination can be as high as 50 per cent and light meter readings will vary with the number of people who are in the room at the time the readings are taken.

MR C. DYKES-BROWN: We have been privileged this evening to hear about the diverse forms of lighting in use on board ship, and I feel that some of these may be new to many lighting engineers. The paper contains a lot of most useful information. The almost unending references to rules and regulations, however, would alarm anyone who had had little or no experience in the marine world, and might give the impression that the requirements are well beyond the ability of the average lighting engineer.

Earlier in the discussions Mr Holmes asked what part this country had played in the development of ship lighting. It will probably be of interest to know that, to the best of my knowledge, the first fluorescent lighting installation on any ship was carried out in this country in 1936. It was of the cold cathode type and many pioneering difficulties had to be overcome before acceptance. There was alarm because high voltages were involved and a number of sea trials were made to ensure that the performance of important equipment was not impaired; this included radio telephone, direction finding and depth sounding apparatus. A number of other installations followed shortly afterwards, including one on R.M.S. *Queen Mary*.

I am glad to see reference is made to the cold cathode type of lighting, but I think most readers would infer from the text that there is nothing in its favour. This is far from the case and as a matter of interest cold cathode lighting is now being installed in the public spaces of four large liners now building in Great Britain. I believe that a total of six miles of tubing is involved.

MR DEREK PHILLIPS: I should like to refer to two remarks, the first in the written paper, and the other verbal.

Under the heading Passenger Ships (Accommodation) the author states—'Sufficient is known about interior lighting practice to enable any lighting engineer to deal effectively with passenger ships . . ', and there follows a reference to a paper on hotel lighting. In the verbal presentation, after a series of pictures of what to me were extremely painful installations, Mr Grundy said, 'As you can see these are all excellent installations, because you wouldn't even know you were in a ship.'

I question the assumption, as common amongst ship architects as amongst lighting engineers, that the interior of a ship should be made to resemble as far as is possible a hotel. The best ships of past periods used the finest interior decorators of their day, working within the limitations of ship construction, to create fine ship interiors in which the passenger never lost the feeling of being afloat. Nowadays with the potential for suspended ceilings, floating walls and modern methods of lighting, it is possible to create the effect of being in a hotel. But this is perhaps questionable in the light of the economics of travel; airlines provide fast comfortable services at less cost than luxury travel on a ship, whilst if one wants to stay in a hotel environment why go to sea at all? Surely the ship traveller of the future is going to be the person who wants time for relaxation in some connection with the sea, in which the romance of a 'sea voyage' is paramount. So why shouldn't ships look more like ships?

MR G. D. BRITTAIN: The author's reference to chartroom lighting is a timely one, and it is interesting to note that corrections to charts are now being made in violet ink to give better readability in red light. This seems to be a problem which has only just begun to come to the attention of chart printers and designers.

In the signalling demonstration the use of rapid incandescence/nigrescence lamps was particularly interesting. I was under the impression that this type had been superseded by the shutter version in view of the difficulty of achieving a good beam pattern with the less compact filament construction of the rapid incandescence/nigrescence lamp.

THE AUTHOR (in reply): I was very pleased to hear Mr Holmes' comments, particularly on the tradition of the sea. Mr Holmes is completely correct when he speaks of this tradition as really ruling the lighting engineer, and I am not in the least surprised to hear of his experience of carbon filament lamps in the Admiralty. On the question of fire hazards there is an international agreement and that is why we find in passenger ships that the regulations are so stringent; I refer, of course, to the International Conference on Safety of Life at Sea 1948, Cmd. 7492.

I hope we have not frightened anybody from going to sea due to our reference to chart-table lighting. A few days ago I was down at Tilbury looking over a new ship that has just come into

commission, and some of the work that the owners are doing as regards their layout on the bridge and the use of chrome or orange screens is exemplary. We may have no fear whatsoever in travelling in any ship, particularly if she is under the Red Ensign.

I was very interested in Mr Holmes' comments on the work in Admiralty Research Report ARL/N5/0360, and I am very much obliged to him for this information.

Mr Chittenden mentioned that shipowners and shipbuilders do not generally call in the lighting engineer at the planning stages, and I would support him in this plea. Ships cost a lot of money, and as they are likely to be in service for 20, 30, or 40 years, I think the owners have every right to demand what they particularly want, and it is our job as lighting engineers to provide them wtih their requirements. I appreciate Mr Chittenden's remarks, and agree that full emphasis of the requirements of crew accommodation should be made, and would specifically refer to the Merchant Shipping (Crew Accommodation) Regulations 1933, SI. 1953, No. 1036, Masters and Seamen: Amendment Regulations, SI. 1954, No. 1660. I feel that these particular Statutory Instruments were probably the results of discussions with the National Maritime Board—which is the established machinery for negotiations and consultation between employers and employees in the shipping industry and which is a model of what such machinery should be. The average life at sea of a merchant seaman is not above ten years, and industrial relations in the British shipping industry is exceptionally good. There has been no official strike in the industry since 1911. It is remarkable, however, that in so far as the master and the navigator are concerned, there are no regulations as to command bridge lighting. For an officer it is one of the most hazardous professions to be in, for if a master mariner makes a mistake in hazarding his ship he has a court of inquiry to face and he can lose his certificate and be ashore without employment.

Mr Dykes-Brown referred to the terrifying regulations. That was the serious intention—that you should be terrified, for they terrified me. I do think seriously that the British shipping industry is so weighted down with all these regulations, that it is a very hard task to find one's way through them. In my opinion, they require very serious attention and general tidying up because so many of them are cross references. On the subject of cold-cathode lighting, Lloyd's regulations demand that you should take great care in the installation of this form of lighting. It is well to remember that a ship is away at sea and if faults arise you have to ensure the safety of the ship's crew as well as the passengers. I feel that cold-cathode lighting has its place where hot-cathode lighting is unsuitable, and likewise I think that in other instances hot-cathode lighting is suitable and cold-cathode lighting would be unsuitable.

Mr Derek Phillips mentioned the question of hotels and ships. Broadly speaking, people travelling by the expensive passenger liners today are not people of a lighting engineer's income status, and these that travel, if you like from Southampton to Cape Town and perhaps New York, travel by sea because of the luxury and don't particularly want to know they are in a ship as such when they are at sea. We know that shipowners are giving consideration to 'cafeteria travel' for people with not a lot of money, and those people, I think, would want to know that they are in a ship. I think architects and designers just as well as lighting engineers have quite a big responsibility in this matter. I mentioned that a few days ago I went down to a particular ship at Tilbury. When I came out of the engine-room and started once again into the passenger accommodation, quite suddenly something began to be familiar to me; then I realized where I was—in the Design Centre in Haymarket. It would seem to me that the Council of Industrial Design is influencing designers so much that we are getting a recognizable style which is noticeable to the layman.

Mr G. D. Brittain's remarks on chart-room lighting are of interest and he is quite right in saying that it has only just begun to come to the attention of chart printers and designers. Mr Holmes has referred to the Admiralty Research Report ARL/N5/0360, and I would particularly refer Mr Brittain to the Journal of the Institute of Navigation, Volume 12, No. 2, April 1959, wherein he will find details of a thorough discussion of the production of charts. Lighting engineers have not to date given a great deal of attention to the lighting of charts, or, for that matter, the whole of command bridge lighting. With the advent of more and different types of radar sets installed in ships for forward navigation, coastal navigation and so on, far more attention will have to be given to this subject. For example, a special system of lighting known as white-minus-amber has been installed in the Port of London Authority Operational Centre, and this excellent system may be regarded as a starting point for this problem. With reference to Mr Brittain's comments on the rapid incandescence and nigrescence lamps, this type has not been superseded by the shutter version because of the different applications involved. Today there is an extremely wide variety of signalling lanterns, each used for a specific purpose.

UDC 612.843.3

A Note on Calculations of Disability Glare, Veiling and Contrast

By J. M. WALDRAM, B.Sc. (Fellow)

Summary

The effects of disability glare and veiling are shown in a new method of plotting object and background luminance, suited to their graphical calculation. The conspicuousness of objects not near the threshold can be estimated by the differences in apparent brightness which they present under the conditions considered.

Disability glare has been shown by Holliday and by Stiles and Crawford, and later workers, to produce an effect which is equivalent to a veil over the scene, and the observer subjected to glare has been found to be just able to discern a low-contrast test object in the presence of glare under the same conditions if the glare source is removed and there is substituted for it a haze veil over the scene. The luminance of the equivalent haze veil is given by

$$G = KE/\theta$$

where G is the luminance of the equivalent haze veil, E the illumination at the eyes and θ is the angle separating the direction of the glaring source and the object of regard. The constants vary according to the experimenters and for various viewing conditions (size and time of exposure of test spot) but for conditions which most closely approach those in real situations, when E is in lumens per sq. ft. and θ is in degrees, G is given in cd/sq. ft. when K is 10 and n is 2.

This formula is of no use by itself. The luminance of the haze veil is not a measure of the glaring effect or an index of how well one can see. In order to interpret it, there must be data of (1), the luminance of the object and of its background, and (2), of the difference in luminance required at these levels for the object to be just visible. (The term 'contrast' is not used, as it is properly a non-measurable sensation of difference. This point is developed later.)

The difference in luminance can be given in terms of the actual values, or of their absolute difference, or of the ratio of the two luminances or of the relative difference (the absolute difference divided by the greater luminance). The latter function is known as Fechner's Fraction and the capacity of the eyes to perceive small 'contrasts' is usually portrayed as a curve relating the just perceptible value of Fechner's Fraction as a function of the background luminance. It is assumed that the background is of uniform luminance and is large enough to determine the adaptation level. Some workers have presented results as the absolute difference of luminance. As a very long range of background luminance is involved, it is plotted almost invariably on a logarithmic scale. A curve of Fechner's fraction is shown in Fig. 1.

The value usually plotted is the laboratory threshold, i.e. the value of the relative luminance difference such that the mean observer will perceive the test object under laboratory conditions on half the occasions on which it is presented. At about twice the relative luminance difference for the threshold, the mean observer will just perceive it every time. For the satisfactory performance of practical tasks with adequate surety, considerably greater differences of luminance are desirable, especially if the observer is not fixated on the test object and has to

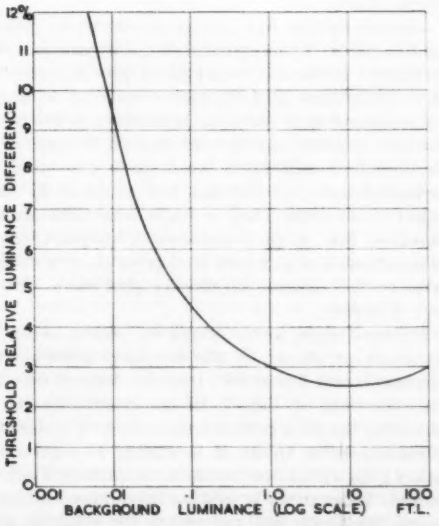
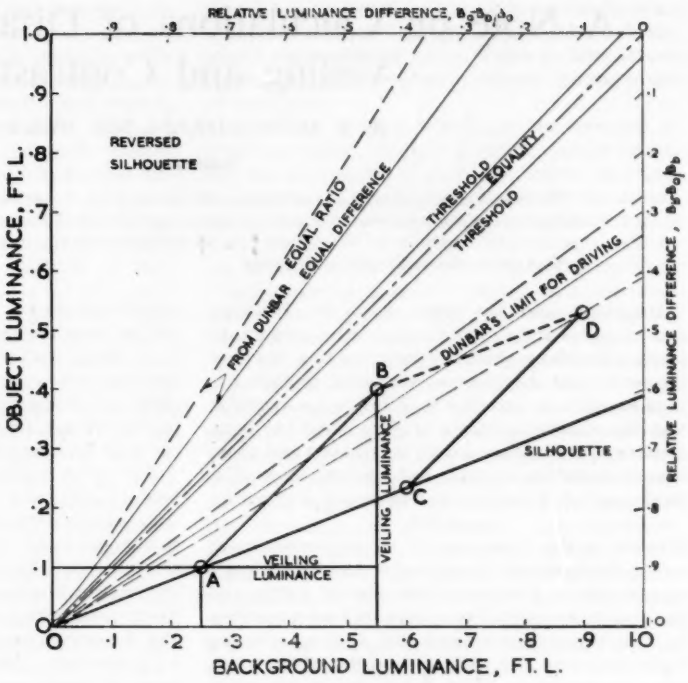


Fig. 1

The author is with the Research Laboratories of The General Electric Co. Ltd. The manuscript of the paper was first received on September 30, 1959.

Fig. 2



find it without external clues, so that it is first perceived extrafoveally: such values must be determined *ad hoc*.

A graph such as Fig. 1 is inconvenient for following the effect of the equivalent glare veil. For this purpose it is more convenient to plot a restricted part of the data in a different way and on linear scales, as in Fig. 2. Here the luminance of the background is plotted as abscissae and the luminance of the object as ordinates. When they are equal, as portrayed by a line through the origin at 45°, the object is invisible. Any straight line through the origin on this graph represents a unique ratio of luminances of object and background, or a unique value of the relative luminance difference. (Fechner's Fraction).

The conditions under which the object is just at threshold are shown by the two lines immediately adjacent to the line at 45°; they are derived directly from the data of Fig. 1. In the conditions represented by the area between these lines the object is invisible; above them, it is visible as light on a darker ground, and below them, as dark on a lighter ground. Three other bounding lines have also been drawn; the lower one represents the limiting conditions for safely perceiving an object as a silhouette under conditions of driving a car at night according to Dunbar[3]. The upper lines have been derived from the lower one, one giving the same luminance difference above equality, and the other the same ratio of luminances: it is not certain which should be taken as the limit. The much wider region between these upper and lower bounding lines may be taken as the region outside which an object will present a contrast adequate for all practical purposes.

The effects of glare, or of a real veiling luminance, can be shown immediately on this graph. Let A be a point representing an object seen against a background of different luminance; as shown, it represents an object of luminance 0.1 ft-L seen against a background of 0.25 ft-L, and presenting a relative luminance difference greater than the limit found by Dunbar. Now suppose that a glare source is exposed having an equivalent veiling haze of 0.3 ft-L (a severe glare source in these circumstances). This luminance must be added to both object and background; it is represented by the line AB at 45°, the point B representing the luminances of the test object and background when a luminance of 0.3 ft-L has been added to that of both. The relative luminance difference of the object was originally

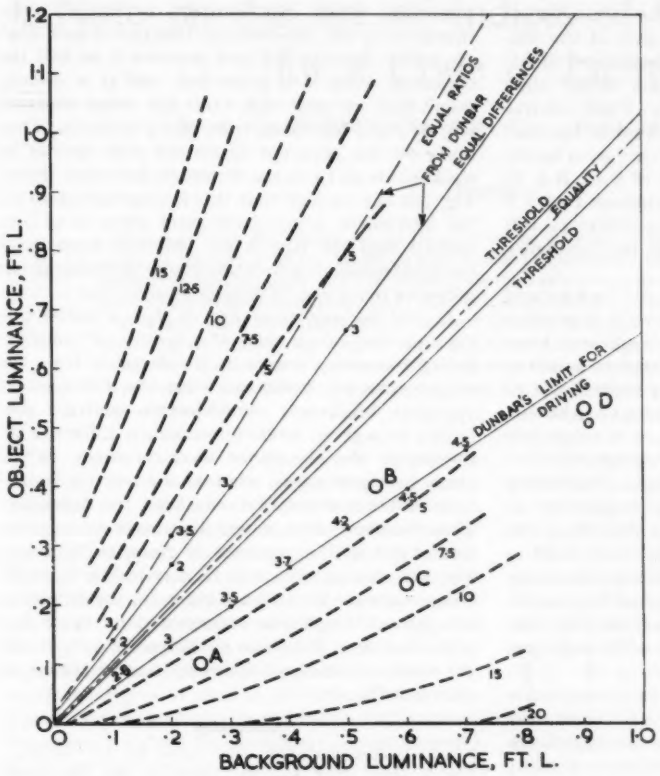


Fig. 3

represented by the line OA; (Rel.lum.diff. $=0.6$) after adding the glare it is represented by OB (0.28) and the value is now within Dunbar's limiting curve and is inadequate for certain seeing.

If the object and background are both illuminated more intensely so that their luminances are increased, keeping the original relative luminance difference the same, the point representing the conditions in the absence of glare will move to one such as C, lying on the line OA produced.

After the addition of glare the point representing the conditions will be at D, where CD is at 45° and represents the addition of a glare veil of 0.3 ft-L as before; D now lies outside the limiting curve, and the object will be visible. The relative luminance difference in the presence of glare is greater than that before increasing the illumination, being represented by the direction OD instead of OB, i.e. 0.4 instead of 0.28. It is however still less than the original value without glare, being represented by the direction OD (0.4) instead of the direction OA (0.6). Evidently it is not possible by so illuminating the object and background to restore the original relative luminance difference, though if the illumination is made very high the final value may be insignificantly different from the original value.

In lighted streets the veil due to glare, even in the more glaring non-cutoff installations, is of the order of 0.1 ft-L. It will be clear from the diagram that a veil of this order of luminance can bring an object within the limit only if it was originally quite close to it, i.e. not well visible anyway. This is most likely to happen in the regions of low luminance, below 0.1 ft-L. Below about 0.02 ft-L even a totally black object does not present sufficient contrast for certain seeing.

It must however be stressed that this diagram is of strictly limited application. It is drawn for the stimuli, not for the sensations: it does not indicate 'contrast' as a sensation. It indicates the conditions under which an object is or is not adequately visible to a given standard, and shows what relative luminance difference it presents. It gives no indication whatever of how conspicuous it is when it is away

from the limit, and no indication whatever of comfort. Consider the horizontal axis of the diagram; it represents the relative brightness difference presented by a perfectly black object upon backgrounds of different luminance. These relative differences are all the same; nevertheless the conspicuousness of such an object will vary from barely perceptible against a background of 0.02 ft-L to clearly conspicuous against a background of 1.0 ft-L. Any given relative luminance difference will appear to give a higher contrast as the luminance level increases.

For the special case of a uniform background which is equal to the adaptation level it is possible to plot the differences in apparent brightness, however, using the curves of apparent brightness due to Hopkinson[4]; in Fig. 3 values have been shown as contours of equal difference of apparent brightness. These curves do give some indication of subjective contrast and conspicuousness, not necessarily very accurately. It is however interesting and satisfying that the difference of apparent brightness at Dunbar's limiting curve varies from only about 3 to 4.8 over the whole luminance range from 0.05 to 0.7. Dunbar's limiting curve probably represents a nearly uniform difference of apparent brightness, though it may not be quite constant; there are reasons for expecting a slight increase with increasing level.

These contours give some idea of the conspicuousness of luminance differences which lie away from the limiting lines and of the change of conspicuousness brought about by glare, though they apply only to uniform fields.

The scale of apparent brightness from which these figures are derived was originally arranged so that unity represents the smallest difference in brightness which can normally be noticed. The threshold is the difference in luminance such that the mean observer will just perceive it on half the occasions when it is presented, and it is usually found that at twice this value the mean observer will be just able to see it on every occasion. Thus unity on the apparent brightness scale should be equal to about twice the threshold difference. From Fig. 3 it can be seen that this is approximately so, the agreement being quite good when it is considered that the figures are obtained from three quite independent sets of observations conducted at different times and in different conditions.

It will be seen from Fig. 3 that a radial line through the origin cuts the family of contours giving increasing values as the distance from the origin increases, indicating that the difference of apparent brightness or subjective contrast presented by a given relative luminance difference increases as the luminance level increases, in the range here portrayed, whereas the relative luminance difference remains constant by definition. Thus the effect of increasing illumination on a given test object in the presence of glare, indicated in Fig. 2 in moving from *A* to *D*, does in Fig. 3 almost compensate for the effect of glare, for the difference of apparent brightness represented by these two points is almost the same, though as already shown the relative luminance difference has decreased, as shown in Fig. 2.

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A Note on the use of Indices of Glare Discomfort for a Code of Lighting

By R. G. HOPKINSON, B.Sc. (Eng.), Ph.D., M.I.E.E. (*Fellow*)

Summary

Freedom from discomfort caused by glare is one criterion of lighting quality. In present codes of lighting practice, tables of permissible brightness of lighting units are the usual method of limiting glare. Such an indirect method effectively bans the use of bright luminaires which when used appropriately may be quite suitable for certain environments.

It is now suggested that a better method of controlling glare is to limit the permissible level of glare directly, in term of levels of a Glare Index, based on recent researches. Provided the value of the Glare Index appropriate to the environment is not exceeded, no limit is put on the luminance of the sources used. Greater freedom in lighting design is consequently permitted.

The major factors which govern discomfort caused by glare have been under study in many countries for some time, with the result that a satisfactory measure of agreement was reached by the C.I.E. Expert Committee in 1959 on mathematical formulation to best fit the experimental data. Field studies on actual installations have also been made over a number of years [1 2 3] and it can be concluded from these published data, and other unpublished data, that good correlation exists between the degree of glare as estimated and as computed from the appropriate glare formula, provided the assessments and the photometric measurements of the installations have been made in accordance with the requirements of the relevant glare functions.

It is therefore a good time to re-consider how best to incorporate in codes of lighting practice firm recommendations on the limiting of discomfort in lighting installations. Such recommendations have been made in previous codes and building regulations [4 5 6]. They have usually been expressed in terms of the limiting luminance, within certain angles of viewing, mounting height etc. of the visible lighting units. Lighting units which were brighter than these permissible limits were therefore not acceptable for use in places where the code might be in force.

This form of codification, while having advantages of simplicity, suffers from at least two major disadvantages:

(a) Strict adherence to the code prevents the use of bright lighting units which may be satisfactory in their proper place.

(b) No account is taken of the varying demands of different environments on lighting quality.

Another form of codification, which may be useful to consider, is the direct limitation of the degree of glare discomfort which can be accepted in any given environment. Provided that this degree is not exceeded, the lighting can be installed in any way and with any units judged by the designer to be appropriate to the environment. Such a system clearly has advantages.

In order to understand how a lighting code could then be devised, it is necessary to recall the way in which glare discomfort can be expressed.

The experimental work has shown that the main effects of glare arise from the luminance of the sources and their apparent size, and their position in the field of view. The glare they cause is 'buffered' by the luminance of the general environment and by the luminance of the areas immediately surrounding the sources. The substitution of the appropriate photometric and geometric values in the so-called Glare Formula results in a numerical value which can be called a Glare Factor (e.g. Harrison 1945) [7] or a Glare Constant (e.g. Hopkinson 1940) [8].

Tables of Glare Factors or Constants have been published which give the relevant link with the degree of discomfort experienced by the 'mean' or 'average' observer of a given population. These degrees of discomfort are expressed in subjective terms. (See Table 1)[9].

This table applies to the average of the population studied in the B.R.S. investigation. The relation between this and the varying sensitivity to glare of the general population has been studied and reported on in detail[10 11].

A code of lighting practice could be based on such

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Table 1

Degree of Glare Discomfort	Value of B.R.S. Glare Constant
Just Intolerable	600
Just Uncomfortable	150
Just Acceptable	35
Just Perceptible	8

a table and its supporting population-variance data. This has in fact been done in the case of building regulations in schools[5], where the nature of the environment and the work are fixed and known.

It is clear, upon thought, that not only is there a population-variance, but also that in practice, as opposed to laboratory conditions, lighting which causes discomfort in one environment may cause little or none in another. In a place where one 'sits and thinks, or just sits' relatively inoffensive luminaires may obtrude on the consciousness and cause discomfort, whereas the same luminaires, used in a place where everyone is busy and preoccupied, may go completely unnoticed. This is one of the most

Table 2

Proposed Limiting Values of Glare Index

Glare Index $= 10 \log_{10} \frac{B_s^{1.6} \omega^{0.8}}{B_b^{1.0}}$ summed for all sources

i.e. Glare Index $= 16 \log_{10} B + 8 \log_{10} \omega - 10 \log B_b$

where B_s is the luminance (ft lamberts) of the source modified by the Position Index[13] for its situation in the field of view to the observer,
ω is the apparent size (in steradians) of the source,
B_b is the general luminance of the environment (ft lamberts).

Location		Glare Index to be not greater than
Schools	Classrooms	16
	Libraries	12
	Staff Rooms	12
	Laboratories	16
	Dressing Rooms	22
	Specialised Rooms (art, needlework)	10
Offices	General Offices	16
	Drawing Offices	12
Domestic	Kitchens	20
	Bathrooms etc.	22
Hospitals	Wards	14
	Laboratories	16
	Operating theatres	10
Shops	Personal service shops	16
	Multiple counter shops	22
Public Buildings	Libraries—racks	10
	—reading rooms	16
	Museums—with showcases	16
	—art galleries	10
	Churches	10
Railway Stations	Platforms	26
	Waiting rooms	20
Factories	General workshops	20
	Specialised workshops	18
	Inspection Bays	18
	Storerooms and racks	26
	Storeroom office	18
	Boiler houses	22
	Power Houses	22
	Garages	22
	Foundries	22
	Laboratories	16
	Precision Tool shop	14
	Paint shop	22
	Packing rooms	18
	Welding shops	18
	Woodwork shops	18
'Amenity' level, not to be exceeded in any environment occupied continually by people		24

important features of a psychological attribute such as glare discomfort, yet it is one which cannot from its very nature be studied under laboratory conditions, and which can be properly investigated under field conditions only by a costly 'social survey'. Nevertheless its importance cannot be ignored nowadays in view of the rapid advances being made in lighting levels.

A start should therefore be made to codify limiting levels of glare discomfort to be based first on the solid foundation of computations from the measured photometric and geometric parameters of an installation, and second (for the present) on the concurrence of experience of lighting practice built up over the years, until such time as complete social surveys can be made to offer a more acceptable scientific substitute for this experience.

In the course of work at the Building Research Station on practical lighting problems knowledge has been gained of the degrees of glare discomfort which cause annoyance in different environments. Some of this information has been gained by direct questioning, some as a result of spontaneous complaints or requests for advice, and some by careful personal appraisal by trained observers. It is rare for there to be any use of the actual word 'glare' by untrained people, for this term is associated more in the lay mind with the sun, car headlamps, or reflections off the surface of water, glass, or polished metal. The words more often used are 'too bright a light', 'too much light', and so on, and it has been necessary to use some freedom in interpretation of the expressions of complaint. From such information ideas have been built up of the probable limits of glare discomfort which present-day practice of good lighting ought to tolerate. These limits have been translated into terms of the B.R.S. Glare Constant.

Recent studies have shown that the numerical magnitude of glare sensation is associated with the logarithm of the luminance of the source when the surround is maintained constant, and with the logarithm of the luminance of the surround when the source is maintained constant[13].

Inspection of the glare formula shows that an argument can be developed in favour of expressing glare limits in terms of a logarithmic scale based on this formula.

Furthermore, studies now being conducted at the Building Research Station, which were reported briefly at the C.I.E. meeting in Brussels in 1959, indicate that the least difference in glare discomfort which can be recognized with certainty by a skilled observer under conditions of direct comparison is also constant on a logarithmic scale. If, in fact, the logarithmic scale of B.R.S. Glare Constant is multiplied by 10 it so happens that one unit on the scale so produced corresponds closely to this just appreciable increment of glare discomfort. Such a scale clearly has advantages for practical use.

A table has therefore been drawn up, listing a selected number of typical lighting environments, giving proposed values, on this new scale, which may be called a scale of Glare Indices[14], and which might form the basis for discussion when formulating a new lighting code.

In order to assist in the interpretation of the above values in terms of glare sensation as expressed in the Building Research Station study, the following values of Glare Index correspond to the described criteria *under laboratory conditions*.

Just intolerable	...	Glare Index		28
Just uncomfortable	...	,,	,,	22
Just acceptable	...	,,	,,	16
Just perceptible	...	,,	,,	10

It does not follow, however, that a lighting installation on a railway platform, of Glare Index = 26, would give almost intolerable discomfort from glare. In that particular environment, where the observer is busy on other matters, such a lighting might not be obtrusive. Again, it is not suggested that by permitting a Glare Index of 22, 'just uncomfortable' glare is considered satisfactory for many industrial environments. In such environments such lighting may be unnoticed, or where noticed, it may cause no annoyance to the workpeople.

As the general public becomes more conscious of lighting quality, the values in the table will have to be lowered, just as the recommended levels of illumination have been progressively increased from time to time. It is also to be hoped that the social surveys, referred to earlier, will eventually be undertaken, so that future tables can be based on their results.

Acknowledgments

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UDC 628.978

Technical Discussion Sessions at the 1960 Summer Meeting

At the Summer Meeting in May 1960 one day was devoted to six informal sessions at which the work of special panels of the Technical Committee was presented, examined and freely discussed. The reports which follow have been prepared by the chairmen of the six sessions and include a summary of the preliminary remarks by invited speakers and a necessarily brief and anonymous summary of the general discussion.

The six subjects are: (*a*) Analysis of the visual task, (*b*) Luminance and glare, (*c*) Modelling and colour, (*d*) Industrial area floodlighting with particular reference to railway sidings, (*e*) Maintenance, (*f*) Lighting calculations.

Analysis of the Visual Task

(Chairman: Dr J. W. Strange)

This discussion was greatly helped by taking place the day after Mr Weston had presented his paper on 'Rationally Recommended Illumination Levels'. His work on visual task analysis was the basis for the current and previous editions of the I.E.S. Code and his work will clearly be important in the revised Code now being prepared.

In opening this discussion, Mr Weston said 75 per cent of the visual tasks that the lighting engineer has to deal with can be covered by the values recommended in the Code but about 25 per cent would need some special examination. It was emphasized that in all cases the lighting engineer should not be content with just specifying levels of illumination; it is the analysis of the task to be done which is important, so that the quality of the light and how it should be applied to the objects of regard can be suited to the particular work that the eyes have to do. A number of factors affecting visual tasks were discussed, including the detail that needs to be distinguished in the field of view, the duration of periods of critical vision, and the motion of the objects to be seen. Estimation by rule of thumb may often give the wrong answer and an example was given of a radio valve assembly job in which 40 per cent of the actual working time was occupied in concentrated critical vision, 30 per cent in less exacting work, while the remainder could be regarded as a visual rest period.

Both the difficulties and the achievements of task analysis were illustrated by a number of actual examples including the lighting of a drawing office. This particular example led to a lively discussion showing that even a fairly standard job of this type could be improved, not so much in the type of artificial lighting provided, as in the treatment of the surroundings such as the decoration of the walls and ceiling, and the use of blinds over the windows.

The lighting engineer of today has to look at the overall task with which he is faced more critically than he did in the past, and reference was made during the discussion to his work as being 'seeing engineering' rather than 'lighting engineering'. He is concerned with what a person is trying to do and to see, not only in the limited visual task itself but in the whole surrounding visual field. It was emphasized that, without wishing to enter the field of industrial ophthalmology, the lighting engineer is concerned with the optimum conditions for the visual task and for the overall comfort of seeing conditions.

The discussion ranged over a wide selection of different tasks to draw attention to the need for detailed understanding of the task. For example, when the lighting engineer has to light a typing office he might think in terms of the illumination necessary to see the large clear type on the keys of the typewriter, ignoring the fact that the most critical task is the pencil shorthand notes on paper which may be viewed at almost any angle from the horizontal to the vertical. A further example of the need for care is the distraction caused by reflections from chromium plated surfaces on some typewriters. This is also seen in instruments used in control panels at power stations. Bright surfaces and glistening meters may give a smart appearance to the control panels but over a period of time they may add appreciably to the visual fatigue.

Some of the detailed work, particularly in textiles, needs very high levels of illumination and it is quite impracticable to achieve such levels over the whole working area; there was a clear need in such cases for the provision of localized lighting to obtain the best results. It was also pointed out that in some of these operations the detection of the fault was made at some distance from the point at which the fault was rectified, so where localized lighting is

to be installed the detailed nature of the processes had to be considered very closely.

A special plea was made during the discussion for help not only in the techniques and methods of task analysis but also in recommendations for instruments for this work. Particular reference was made to the need for recommended lightmeters, brightness meters and reflection factor gauges.

The main part of the discussion may be summarized by saying that the lighting engineer should stop offering lighting schemes based on illumination levels only, but should concentrate more and more on the quality of the lighting. An important reason for a detailed interest in the basis for the Code values by the lighting engineer is the need for widespread practical experience, to validate the recommended levels of illumination. He should also aim to reveal by the quality of the lighting what particularly needs to be seen as well as to achieve a satisfactory visual environment. On the other hand, there is a shortage of subjective response data which limits the ability of a lighting engineer to prescribe the lighting required. It was suggested that the Technical Committee should sponsor study of the discrimination of detail with colour contrasts, with moving detail and time restrictions and with the age and experience of the observer, before pressing for really comprehensive analysis of the visual task.

To quote Domina E. Spencer (*Illuminating Engineering*, December 1959), '. . . specification of quantity without specification of quality is visually meaningless.'

Luminance and Glare
(Chairman: Mr J. G. Holmes)

In this discussion, the task of the lighting engineer was under analysis, and the present proposals for glare assessment in a new I.E.S. Code were described and examined.

The present I.E.S. Code gives recommendations for the amount of illumination desirable for a wide variety of visual tasks in a wide variety of environments; the figures are based on the rational system put forward by H. C. Weston and on general good practice. These recommendations are in steps of about 40 per cent and the figures are accurate to about 50 per cent either way.

In order to take full advantage of this illumination, the state of adaptation of the eyes and the degree of discomfort glare must be controlled; the work of Petherbridge, Hopkinson and others has enabled us to express this in numbers, again with an accuracy of about 50 per cent either way.

It is important to realise that we can specify, can calculate and perhaps can measure glare with about the same accuracy as we can specify illumination levels for a given task. It is a subject of growing importance because with rising levels of illumination and of surround luminance, the margin of safety before running into glare troubles is growing narrower. One of the advantages of having more light is the amenity value, but this advantage can be counter-balanced or even cancelled if the additional light is accompanied by additional discomfort glare.

Glare is not entirely a matter of luminance, although the two are distinctly linked. Glare is also a matter of size, of contrast ratio, of illumination level and a number of other factors including the nature of the environment. It may be that the present revision of the I.E.S. Code will indicate some acceptable glare levels for different places, different types of interior, and different tasks in much the same way as it indicates reasonable illumination levels for different places and tasks. How is this to be done? How are we to find a 'Glare Index' which will represent the degree of glare? What does the lighting engineer need to enable him to apply the knowledge of the experts? These and similar questions were examined in the informal discussion on 'Luminance and Glare'.

Mr P. Petherbridge opened the discussion by referring to Ward Harrison's question in 1936 'What is wrong with our 50 f.c. installations?' and he examined the factors which influence discomfort glare leading to the basic equation:

$$G = \sum \frac{Bs^p \cdot \omega^q}{Bb^r} \cdot f(Bi) \cdot f(\theta)$$

where Bs is the luminance of the glare source
- ω the apparent (angular) size of the source
- Bb the luminance of the general background
- Bi the luminance of the immediate surround to the glare source
- θ the angle between the glare source and the line of sight

p, q and r are numerical constants
and G is a Glare Constant whose magnitude can be related to the degree of visual discomfort.

In the 1955 Code, this formula had been used with values of 1·6, 0·8 and 1·0 for p, q and r respectively, but the conclusions were so greatly simplified that the recommendations in the Code were not treated very seriously in practice. In the new revision of the I.E.S. Code, the same sort of formula is proposed, but treated in greater detail so that it can be put to more practical use. The four criteria of glare are likely to be as follows:

CRITERION	GLARE CONSTANT G	GLARE INDEX
Just intolerable	600	28
Just uncomfortable	160	22
Just acceptable	40	16
Just perceptible	10	10

The Glare Index is a simple logarithmic scale, calculated as 10· log G. Two units on this scale are about the smallest glare interval likely to be distinguished in practice.

It may be misleading to use descriptive words and so a new Code would only refer to the numerical values, in even numbers from 10 to 30 in order of increasing severity. The recommendations in the Code could be on the lines of the following table:

LOCATION	MAXIMUM GLARE INDEX
Factories	
Precision tool rooms	14
General	20
Storerooms and racks	24
Offices	
Dawing Offices	12
General	16
Schools	
Classrooms, laboratories	16
Cloak rooms	22

Mr H. Hewitt described the work of the Luminance Study Panel of the I.E.S. Code Committee which had critically examined over one hundred installations during the past year and which was trying to find how the lighting engineer could apply the criteria for glare. He found the names of the four criteria difficult to remember and he offered four pictures of the 'Four Just Men' (see below), with acknowledgment to the artist, Mr C. H. Phillips.

The calculation of the Glare Index was not unduly laborious; one could work out in advance the Index for a given type of fitting in a given size of room and one could then add in the corrections for the flux output, for the size of fitting and for the background luminance appropriate to any particular installation. Mr Hewitt took an office as an example and, with a familiar type of lighting installation, derived a calculated Glare Index of 15·8 which was gratifyingly close to the recommended maximum of 16·0. There were some snags such as the effect of non-uniform luminance, the immediate background, the spacing/height ratio and so on. The best technique for making the calculations was still being examined and so details are not given in this report. It may eventually prove possible to classify practical commercial fittings so that they can be codified and so that the labour of calculation can be reduced, but this problem is not yet solved.

The use of a Glare Index can be criticized as being negative or restrictive and it was suggested that the lighting engineer ought to be enabled to design in a positive way, to prescribe for sparkle or for brightness contrast. The proposals for limiting the Glare Index would be a discipline for the fittings designer and we did not yet know how to turn our knowledge of glare to a constructive end.

There was a lively and critical general discussion in which fifteen members took part.

One subject of discussion was the numerical scale of Glare Index. The idea of reducing the large numbers of the Glare Constant to a more convenient set of numbers was generally welcomed, but there were several suggestions for the form of the scale, such as a reciprocal scale (a scale of unobtrusiveness) which might have a greater range than 2·8:1. The scale ought to have a mathematical basis so that graphical or slide-rule methods of calculation could be possible, and the proposed scale seemed to meet this requirement.

Having accepted the idea of a Glare Index scale, the discussion turned to its use. Although further study of the glare problem would undoubtedly improve our knowledge and understanding, the

JUST INTOLERABLE

JUST UNCOMFORTABLE

JUST ACCEPTABLE

JUST PERCEPTIBLE

Glare Index scale should be brought into use as quickly as possible. There were many people involved in lighting, as designers and as users, and it was thought better to start soon with the basic essentials, with as much accurate information as possible, and then to improve the recommendations later. Although we are not yet ready to write a full 'luminance code' and even the table given above may be too ambitious, it was generally agreed that we should put our knowledge into the new I.E.S. Code rather than wait five years for the next revision. It was also important to avoid over-simplification which would lead to inaccuracy as well as to misunderstanding.

The restrictive effect of the Glare Index scale was criticized. Several members wanted some guidance for amenity, some reference datum for sparkle and contrast, some encouragement to provide brilliant patterns, with warnings when particular difficulties were likely to arise for sustained or casual tasks. Some general guidance on values of reflection factor and its effect on glare would be welcome. Cluster fittings and luminous ceilings were popular and yet were sometimes the source of considerable glare, yet these could not easily be assessed in the proposed system. It was, however, realised that the first publication of the Glare Index scale would relate to working areas and to certain specific tasks rather than to decorative surroundings; an example was given indicating the difficulties in guiding interior decorators in the balance of luminance and area.

It was noted that the introductory speakers had not referred at all to daylight glare, which was often as great a source of discomfort as artificial light sources. Reflected glare was also a real factor, not covered by the proposed system. These factors would doubtless be studied and might in due course be brought into the Glare Index system.

In summing up the discussion, Mr J. G. Holmes made three points: firstly that the Code should not over-simplify the problem as in 1955, secondly that the lighting engineer will have to make many laborious calculations on glare just as he now does on illumination, and thirdly that the designer will have to be concerned with the effectiveness of glare control just as he now is with the effectiveness of light output. The present proposals are an advance on which the Luminance Study Panel is to be congratulated, and their publication in the I.E.S. Code would be welcomed.

Modelling and Colour
Chairman: Mr H. R. Ruff

Opening the discussion, Mr M. W. Peirce, Chairman of the panel dealing with modelling and colour, emphasized the necessity for courageous use of lamps to give patterns of light, shade and colour in order to avoid monotony and to achieve attractive lighting. He dealt particularly with the dramatic effects obtained from the floodlighting of architecturally interesting buildings, illustrating various points with slides of the floodlighting of Fountains Abbey, which had been enjoyed by the members on the previous evening. Other examples included the use of pastel colours inside a cathedral.

Continuing, Mr R. L. C. Tate concentrated on day-to-day commercial applications. He suggested that the preference for modelling from side lighting might be due primarily to living in a northern latitude but it was accepted that top lighting, which gives horizontal modelling, was generally unpleasing and that even in tropical conditions lighting from above was limited to a short time of the day.

The meeting dealt first with the floodlighting aspects; it was considered that there was a wealth of architecture in this country where such lighting could add greatly to interest and beauty. The application of colour necessitated a close analysis of the atmosphere to be created. Generally, pastel shades were more effective, but one speaker advised that very strong colours could be used in certain circumstances to create striking contrasts provided that they were used for short times; there might be some relationship between the saturation of colours and the time they were in use. The lighting engineer could gain much from trials with colour photography, and by reference to artistic and photographic studies as well as in the special presentation fields of theatre and television lighting.

The need for guidance on what was considered probably the larger and more difficult task of introducing modelling and colour into everyday lighting was emphasized. A number of slides were shown illustrating the effectiveness of modelling and colour for certain basic tasks, and it was agreed that integration of the lighting with the decoration was essential. Work for the British Standards for paint colours was described, and it was suggested that lighting engineers should persuade paint manufacturers to supply them with the large professional samples in order that lighting effects could be more satisfactorily examined. Often, sufficient modelling could be introduced by satisfactory decoration schemes and the modern tendency to avoid large areas of saturated colours in favour of pastel shades with small areas of bright colours for accent was generally helpful to good lighting practice.

The kind of lighting used in a photographic or artistic studio could not be readily applied to other

interiors since the lighting engineer had to provide modelling and colour for dynamic conditions where people were moving. It was essential to analyse the visual scene and so determine what should be emphasized and how this should be done to be both attractive and effective.

There seemed to be a general wish to enliven artificial lighting. The growing use of special schemes with multiple lighting circuits was described; one elaborate installation which enabled the lighting in a restaurant to be slowly changed over three hours from high intensity to starlight effects showed the possibilities that could be achieved with modern equipment.

It was considered that there was a need for some new definitions and possibly some additional units such as a modelling index to help calculation, together with a tablulation of some of the factors necessary to achieve specific effects. Amplification of the Code to give further guidance on both modelling and colour would be appreciated.

Industrial Area Floodlighting, with particular reference to Railway Sidings

(Chairman: Mr P. Hartill)

The discussion was opened by Mr Imrie Smith who said that the special characteristic of industrial area floodlighting is that we have to consider its effectiveness for operatives working within the compass of the beams from floodlights, while the normal technique for floodlighting applied to the illumination of a spectacle viewed from an external position. It is already established that there are several advantages in lighting marshalling yards or similar industrial areas with floodlights mounted on high towers, usually 100 to 200 ft; these include extensive coverage by relatively few lighting units, avoidance of glare, less excavation for cable runs and simplification of maintenance. It is, however, important to select suitable positions for the towers and not merely to place them where expedient. Coverage of the area alone is not enough; the direction of the incident light has considerable bearing, both upon visibility and upon the avoidance of shadows. In this connection it would be helpful if the lighting engineer could have freedom to select the positions of towers, subject only to a regulation minimum clearance from the track. Assuming reasonable freedom in this respect, the spacing/height ratio should generally not exceed 7:1 preferably 6:1, and the aim should be to ensure that light was incident from at least two directions at each working point. With uni-directional lighting, visibility is generally unsatisfactory unless this is supplemented by diffusion from adjacent buildings, etc., of reasonably high reflecting properties.

In the discussion, many useful contributions were made, both by lighting engineers and by users. It was evident that there was no simple means of specifying the general requirements for a floodlight installation, because of the wide variety of subjects. It was a mistake to regard the measurement of horizontal illumination as a criterion of effectiveness. Examples were quoted of illumination values of 0·5, 0·3, 0·15 and 0·08 lm/ft^2 which were stated to be satisfactory for railway sidings under certain conditions, but this did not necessarily mean that such values were in themselves to be regarded as a satisfactory yardstick. They did serve, however, to give some indication of the total useful lumens provided by the floodlights and it might well be better to specify 'total useful lumens' rather than the actual flux density on any particular plane. The importance of lighting the vertical working faces of railway wagons was stressed, but vertical illumination was no more satisfactory than horizontal as a criterion and there was also the added difficulty that at any one point there was an infinite number of vertical planes.

In the definition of the useful light output from a floodlight, it was considered that the present method of measuring 'beam angle' could well do with revision. The definition adopted in the U.S.A. was simpler to use than the British, but it might well be of advantage to make a completely new approach to this problem and evolve a better way of determining coefficients of utilization for floodlighting.

It had been found by experience that there was no disadvantage in using high-mounted floodlights in conditions of low-lying mist or fog. If the density of the fog was too great, no form of lighting would be of any use, while in less severe conditions the diffusion of the light by the fog was no less satisfactory for vision than low-mounted lighting units. It was of course important to avoid glare or confusion with signal lights for drivers of trains passing through or near railway sidings. On hump sidings, it was also important to screen the floodlights from operatives at the control positions.

It was particularly requested that action should be taken to produce a Code of Practice for this form of lighting and although many problems would have to be thrashed out before a Code could be produced, the need was urgent. At present there was a wide diversity of watts, lumens and costs in the various schemes prepared by lighting engineers and it was very difficult for users to specify their requirements in precise terms.

Maintenance of Lighting Installations

(Chairman: Dr H. H. Ballin)

This discussion was the only one of the series which did not arise from the work of a panel of the Technical Committee, but the large attendance and the keen discussion showed clearly that the subject merits urgent attention. It was hoped that the Technical Committee will give it early consideration.

In introducing the subject, Mr Bellchambers said that many experienced lighting engineers seem unaware of the considerable amount of data already available in the technical press and particularly in the paper 'The Maintenance of Lighting Installations' by Robinson and Strange in the 1955 *Transactions*. The conditions vary so much from place to place and from industry to industry that it is not easy to make any valid generalizations, but the various aspects of the problem could be discussed under the following headings:

(1) Design of lighting equipment
(2) Importance of cleaning
(3) Economics of maintenance
(4) Group replacement
(5) The problem of putting the story over.

(1) *Design of lighting equipment*

Mr McCulloch emphasized the importance of correct design. He had some home truths for fittings manufacturers in general regarding the serious nuisance which loose screws, etc., could constitute. He also put forward the suggestion that fittings should be so designed that even unskilled labour could replace faulty control gear, but against this, the suggestion was made that control gear was now so good that it should not need any replacement at all. In reference to dust covers, he suggested that a new approach should be made to see whether new materials could not be used, as most existing designs seemed to 'breathe' after a relatively short time.

There was agreement that lamp manufacturers had gone a long way towards the ideal of improving the maintenance of lamps and fluorescent tubes and although work was still continuing it was clear that a very small proportion of the total depreciation of lighting installations was due to the lamp itself. On the other hand, the development of reflector lamps, both tungsten filament and fluorescent, was likely to reduce the effect of dust and dirt and these lamps should therefore make a considerable contribution towards better maintenance of lighting installations. Various points regarding the design of lighting fittings were raised, including the suggestion that overlamp reflectors should be used in preference to ordinary industrial reflectors. Curves derived from specific installations indicated that ventilation of fittings had reduced the light losses by 25 per cent.

Reference was made to a recent E.L.F.A. publication on street lighting equipment which had proved extremely useful and it was suggested that a similar report on industrial lighting fittings should be prepared.

(2) *Importance of cleaning*

The difficulty of any generalization was particularly noticeable on the subject of cleaning and the suggestion was made that users should be encouraged to submit to the Technical Committee details of their own cleaning schedules so as to obtain the widest possible range of information. Curves from specific installations showed that with a two-monthly cleaning schedule the wastage of light could be halved compared with a four-monthly arrangement. The maximum period in the cotton industry was three months. Information was given about an air conditioned factory where the accumulation of dirt was extremely small and where cleaning and relamping once a year proved the best solution.

(3) *Economics of maintenance*

Better protection of fittings to reduce the need for maintenance was possible but usually proved more costly initially.

The important point was made that it was the interrelation of initial and running costs which was the major consideration and not simply the initial cost, but it was agreed it would be somewhat difficult to convince users to spend money on maintaining a lighting installation at its proper value. As a rule-of-thumb suggestion, a reduction of illumination below 70 per cent of the design value was the signal for action. Various speakers suggested that it would be desirable to produce evidence of reduced productivity with less lighting; this was, of course, the converse of the case for better lighting, and it was hoped that the revised I.E.S. Code might stress this important point.

(4) *Group replacement*

There was considerable discussion on group replacement of lamps and it was encouraging to find that many members had either used it or convinced their customers to institute it. It was generally agreed that group replacement was worthwhile, particularly as the labour cost of replacing individual lamps was stated to be, in many cases, as much as 18*s*. 6*d*. or 20*s*. As an example, in a street lighting installation group replacement

of lamps had reduced lamp failures in service to 1/10th of the previous figure.

(5) *The problem of putting the story over*

Many agreed that this was a major difficulty. Manufacturers who preached maintenance were often suspected of having ulterior motives, but consistent maintenance was so important that education through the agency of the I.E.S. would be of great value.

In conclusion, Dr Ballin expressed the view that the meeting had been extremely useful and he hoped that the Technical Committee would be able to gather much of the available experience and to publish a report in the near future.

Lighting Calculations

(Chairman: Dr R. G. Hopkinson)

Though this subject was highly specialized, it attracted a large and active audience who showed that in spite of its highly technical nature, it was above nobody's head. It was encouraging to realise that members of this Society are ready and eager for technical material of the right kind, having a direct bearing on their work, and in this instance were keen to discuss problems of engineering mathematics.

Mr Robinson gave a clear summary of the aims of the Lighting Design Data Panel and how they set about achieving them. After reviewing the basis of the Harrison-Anderson method, he explained that the whole edifice of this method was based on a quite elementary photometric background. The Panel had had the choice before them between a modified Harrison-Anderson method, brought up-to-date by modern inter-reflection theory, or the scrapping of the Harrison-Anderson method and the building up of a new method based particularly on the zonal factors of Jones and Neidhart. After considerable thought, the panel had decided to go for the Jones-Neidhart method but to modify it in certain ways which he explained. The panel felt it was much better to adopt a logical system based on a sound theoretical approach rather than to accept the basic limitations of the Harrison-Anderson three-curve method.

It was at this point that the presence of Mr Croft, who has a different point of view, was missed because it had been his intention to indicate the advantages of an improved three-curve method. Extracts from a written contribution by Mr Croft were read, indicating that there was no theoretical disadvantage in using a three-curve method, provided that a modern theoretical treatment was used in the working. He drew attention to the work being done in the United States, particularly by Potter, and asked that further study should be given to the use of a three-curve method such as had been adopted by Simons and by himself.

In discussion, it became clear that the general feeling was with the L.D.D. Panel in their decision to go ahead in the way that they had. It was recognized that their terms of reference had not been to solve all the problems of the calculation of illumination levels but to deal specifically with the determination of coefficients of utilization. They had decided to tackle this specific job in the light of the considerable amount of new information which had become available in the last ten or twenty years, particularly in the calculation of inter-reflections and in full knowledge of the advantages of a modernized three-curve method. Although their method was not perfect, it was felt to be the best to meet the present day requirements. On the other hand the Harrison-Anderson method has given satisfaction for thirty years, it is easy to use, and it is very rare that anybody is able to do enough checking to detect any errors. Naturally lighting engineers will want something a great deal better before they are prepared to give up a method which has become almost second nature to them.

It also became clear that the success of the new method depends entirely on the willingness of the manufacturers of fittings to supply the necessary design data. In this respect there may be some reluctance on the part of some manufacturers who would have been more ready to co-operate in a modified three-curve system. The Society clearly has some promotion work to do here among manufacturers, if the British Zonal Method is to receive universal application.

Mr Robinson made one or two very important points in connection with the British Zonal Method which need to be thoroughly understood, and of these the cavity principle is perhaps the most important. One of the difficulties in dealing with lighting calculations is to make suitable allowance for the suspension of fittings from the ceiling. The L.D.D. Panel has adopted Dourgnon's proposal by which all fittings can be considered as ceiling-mounted, whether they are suspended from the ceiling or not, and by means of a simple transformation, an assumed value for the ceiling reflection factor is taken and the ceiling is assumed to be at the actual height of the light centres of the fittings. Another device is the allowance which has to be made when the light sources are not symmetrical but are linear, so that linear sources can be fitted into the British Zonal Method without any serious error. Further, the spacing/height ratio can be calculated from the square root of the illuminated area per fitting. By these means, we may avoid

some of the basic objections to the Jones-Neidhart system.

Mr Robinson then went on to explain the proposed simplified method devised by the Panel, intended for routine lighting calculations to save time when detailed figures are not required. The object was to provide a method as quick as the Harrison-Anderson method but which would be linked to the full British Zonal Method. In this simplified method, ten tables of figures will be prepared giving the relationships between room index and direct ratio for ten representative light distributions and an additional table will deal with the upward component. It would be the duty of a manufacturer to indicate which of the ten tables applies to his particular fitting.

This simplified method came in for some criticism. Many felt that it is a step in the wrong direction. Mr Croft in particular in his written contribution gave a clear indication that this attempt to pander to the 'non-engineer' was a great mistake. It was no improvement over the old method and would never be used as a substitute for it. Mr Robinson, however, stood his ground and he may in the long run be proved to be right. The Panel showed its awareness of the difficulty in producing a simplified method and there is a great deal to be said for their desire that this simplified method should be closely linked to the complete system.

The discussion then moved on to two very important and basic points. Firstly, how to determine the average illumination in an installation in order to compare it with the calculated values; in other words, how precisely can it be demonstrated that a specification has been met.

Several speakers reported measurements which they had made in installations and the techniques which they had used to determine the 'average illumination'. Mr Burt gave an account of measurements which were being made in his organization to try to find a standard method of measuring the average illumination in an installation. He pointed out, as did subsequent speakers also, the extent to which the errors could mount up, for example in the determination of average reflection factors of the room surfaces. He urged that the Society should give clear guidance, possibly in the new I.E.S. Code, as to how the measurements of average illumination should be made. In written contributions the further point has been made that measurements have to be related to a particular point on the lamp life curve, on the maintenance depreciation curve, and also that account has to be taken of the voltage on the supply points when measurements were taken and the checking that the installation is, in fact, properly adjusted. It was pointed out that official bodies who pay for the installation may easily check within a few days of completion and obtain values with a clean job and lamps operating at their initial output. On the other hand the Trade Union side could quite easily go and take measurements some considerable time afterwards when depreciation has occurred and the lamps are no longer giving their initial output. Here again the Society has a considerable task in specifying clearly when and how measurements should be made.

The second point, certainly of equal importance, was on the question of accuracy. Several speakers and some subsequent written contributions deprecated the use of the term 'accurate', and the term 'realistic' was one which was proposed as an alternative. It was pointed out that there were two conflicting aspects of this problem of accuracy. First of all, the eye is not able to appreciate very small differences in average illumination. While the engineer measures his illumination linearly, the eye sees logarithmically. The acoustic engineers have already recognized this by the general use of their scale of decibels, whereas lighting engineers have not yet adopted scales of apparent brightness. Attention was drawn to the paper given by Weston the day previously, in which he had shown that the just-useful steps on the illumination scale should be not less than 50 per cent. This, in the opinion of some speakers, indicated the degree of accuracy which was necessary in lighting calculations. On the other hand, other speakers, particularly those concerned with the actual installation of lighting, pointed out that they had a problem of meeting a specification precisely, even if this specification was drawn up in an unnecessarily precise form. If, for example, the specification called for 30 lumens per square foot, it was up to the engineer to produce 30 and not 25 or 35; if he gives only 25, he is criticized for not giving the light necessary for the work which people are going to do, and if he gives 35, the customer will say that he is being overcharged for an installation more lavish than the specification required. After much discussion round this point it was agreed that the Society ought to indicate some standard practice to the people who make these specifications, so that it is quite clear that the limits between which the installation can lie are realistic.

It was concluded that the problem of lighting calculations needs to be dealt with under three headings:

(*a*) Specification
(*b*) Calculation
(*c*) Verification.

The L.D.D. Panel had dealt with the second satisfactorily and further work was required, leading to Society recommendations on the first and the third headings.

Several speakers were able to outline the methods which they had used in their own lighting calculation work, and it was particularly interesting to note the various methods which had been used to adapt and simplify modern inter-reflection theory to the problem. The calculation of daylight illumination was briefly mentioned by one speaker, but the minds of the audience were not with him, and the discussion soon moved back to the problems of artificial lighting. This was perhaps unfortunate, because it would undoubtedly have been most useful to develop the close link which should exist between daylight and artificial lighting calculations, and particularly if the discussion could have moved on to the estimation of luminance, where both types of lighting meet and where both can employ the same basic method of calculation. However, the time for discussion was insufficient to examine these more forward-looking problems.

Since the meeting, a number of contributions in writing have been received from members of the audience who were crowded out, and these have been passed to the L.D.D. Panel for consideration. The authors might well consider offering these contributions as letters to the Editor of *Light and Lighting* because they contain a great deal of very useful suggestion.

It was clear that these discussions served a most useful purpose in giving members an idea of what the Society is doing in the technical field and particularly in giving them the opportunity of expressing their own points of view at a stage where their suggestions can be used by the Technical Committee. There is clearly a lot of careful thought going on in the body of the Society and it is to be hoped that some members who only spoke under the shield of anonymity will be encouraged by the warm reception which they received to develop their ideas and present them to the Society for a more formal discussion at a sessional meeting.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership of the Society:

Sustaining Members

Banks Electrical Wholesalers Ltd., Wilton Street, Holderness Road, Hull.
Representative: M. Pack.

Mullard Blackburn Works Ltd., Philips Road, Blackburn, Lancashire.
Representative: H. Kirkman.

Corporate Members

Bayliss, C. L.	61 Hartismere Road, London, S.W.6.
Bennett, F. G.	W. A. Smith & Co. Ltd., East Silvermills, Edinburgh, 3.
Birkhoff, A. J.	1280 Bridge Road, Oakville, Ontario, Canada.
Bucks, B. D.	G.E.C., Magnet House, Kingsway, London, W.C.2.
Cahill, P. T.	43 Park Chase, Wembley, Middlesex.
Canham, A. E.	Electrical Research Association, Field Station, Shinfield Road, Shinfield Green, Reading, Berks.
Carvell, D. A.	15 Dovedale Road, New Brighton, Lancs.
Chapman, E. G.	99 Layhams Road, West Wickham, Kent.
Charman, K. W.	12a Church Close, Locksheath, near Southampton.
Churchyard, E. B.	A. E. Reed & Co. Ltd., Group Office Building, Larkfield, near Maidstone, Kent.
Coope, L.	Briar Cottage, Hightown, near Liverpool.
Ederisinghe, D. F.	27 Brimsdown Avenue, Enfield, Middlesex.
Elleray, F. N.	102 Arran Avenue, Blackburn, Lancashire.
Fernandes, J. A.	P.O. Box 1191, Nairobi, Kenya Colony.
Fitzsimmonds, C. A.	'Casa Mia', Coolgardie Road, Ashford, Middlesex.
Gadd, J. E.	Glan Hydryd, Cymau, near Wrexham, Denbighshire.
Gordon, W. W.	P.O. Box 356, Limbe, Nyasaland.
Gray, J. S.	44 Lemon Grove, Newton West, Bulawayo.
Grosvenor, R. J.	39 Stagelands, Langley Green, Crawley, Sussex.
Gupta, J. K.	Co-ordinating Division, Electricity, Water and Gas Dept., Govt. of Kuwait, Post Box No. 12, Kuwait, Arabia.
Guscott, W. J.	Commercial Dept., South-Western Electricity Board, Electricity House, Colston Avenue, Bristol, 1.
Hawkins, S. H.	6 Cromwell Road, Beckenham, Kent.
Illidge, R.	48 Greenwood Road, Sheffield, 9.
Jansen, J.	Blokuenlaan 22, Waalre, Holland.
Jones, S. J.	2 Marland Avenue, Cheadle Hulme, Cheadle.
Kirkhope, W.	Cameroons Development Corporation, Bota/Victoria, British Cameroons.
Krishnamachar, K. T.	76 South Audley Street, London, W.1.
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